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January 23, 1987

Ms. Janis Wheatley
Acquisitions Coordinator
Micromedia Limited
158 Pearl Street
Toronto, Ontario
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Dear Ms. Wheatley:

Thank you for your note of December 16, 1986 advising that pages were missing from two publications issued by this Branch:

- Dual Fuel Natural Gas/Diesel Conversion System in Four Stroke Engines
- Characterization of Canadian Automotive Fuel Economy and Policy Initiatives 1985-1995 - ABRIDGED VERSION

With respect to the former document, we are returning it to you with the missing page inserted. In the case of the second report, please note that the document is available to the public in an abridged edition only. The information contained on the missing pages is confidential and cannot be provided. Your copy of the abridged report is also enclosed.

If you have any other questions, please let me know.

Yours sincerely,

A. Dunn
Administrative Clerk

Canada

Characterization of Canadian
Automotive Fuel Economy and Policy Initiatives
1985-1995
ABRIDGED VERSION

Prepared for Energy Mines and Resources

Prepared by: Energy and Environmental Analysis, Inc.
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Arlington, Virginia 22209

March 1985

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1. INTRODUCTION

Transportation energy use accounts for 24 percent of total energy consumption or 55 percent of petroleum product consumption in Canada, and its share of petroleum use is predicted to rise in the future. In order to control energy use in this sector, Canada has adopted a voluntary program that required each manufacturer to attain a goal of 8.6 l/100 km for its Corporate Average Fuel Consumption (CAFC) of new vehicles sold in 1985. These fuel economy goals are set to expire in 1986 and there is concern in the Canadian government about the direction and thrust of future policies to improve fuel economy.

The current size of the Canadian market is such that Canadian domestic manufacturers sell vehicles that are nearly identical in design to those sold in the U.S. The U.S. market has shown some recent trends that indicate potential problems in future fuel conservation efforts. Fuel prices have declined considerably in real terms in the U.S., and consumers in the U.S. have been buying larger vehicles and high performance options in greater numbers. The manufacturers have responded by upsizing their vehicles and delaying or cancelling plans to build technologically advanced fuel-efficient cars. Unfortunately, the same vehicles are being sold in Canada inspite of the fact that Canadian fuel prices remain close to their historic highs. As a result, Canadian policies to improve fuel efficiency are being impaired by events beyond Canada's control. Moreover, there has been considerable recent speculation over a possible continued decline in fuel prices for the next decade.

Future policies to improve (or prevent any substantial increase) in fuel consumption of new vehicles can be implemented only if a clear understanding of future fuel consumption under a "non-intervention" scenario is available. The impact of future policies can be measured against

this "non-intervention" baseline scenario, and the forecasts of fuel consumption can be used to determine if: (a) any policy is necessary and (b) a particular policy is cost-effective. The forecast of fuel economy under a non-intervention scenario is sensitive to fuel price and economic growth assumptions; thus, the influence of policy can be gauged against alternative assumptions on fuel price and economic growth.

The approach used in this study to enable consideration of alternative policies was to forecast fuel economy under several fuel price scenarios that reflected "best" expectations as well as the "worst" case for high and low fuel prices. The forecasts of new vehicle fuel consumption under all of these scenarios provided not only the future path that can be reasonably expected but also the upper and lower bounds that could potentially occur in the future, so that any policy initiative could be evaluated over the range of possible trends in fuel consumption. The fuel price scenarios were specified by EMR, Canada and were based on the "official" forecasts of this Canadian and U.S. governments. As described above, the level of fuel efficiency in Canada is dependent on both U.S. and Canadian fuel prices and the different scenarios reflect different combinations of U.S. and Canadian fuel price paths. The scenarios are:

- 1) The Base Case, where U.S. and Canadian prices follow the path of current (1984) best expectations. The price paths show Canadian prices remaining flat in real (inflation adjusted) terms between 1984 and 1995 and U.S. prices remaining flat in real terms between 1984 and 1988, and climbing thereafter so that the 1995 real price is approximately equal to the 1982 price.
- 2) The Steady Price Increase Case, where Canadian fuel prices rise linearly between 1985 and 1995 such that the 1995 price is 50 percent higher than the 1995 price in the Base Case. Prices in the U.S. are assured to stay the same as in the Base Case.
- 3) Falling Oil Price Case, where both U.S. and Canadian prices **decrease** linearly between 1985 and 1995 such that the 1995 price in each country is 50 percent below the 1995 Base Case price in that country.

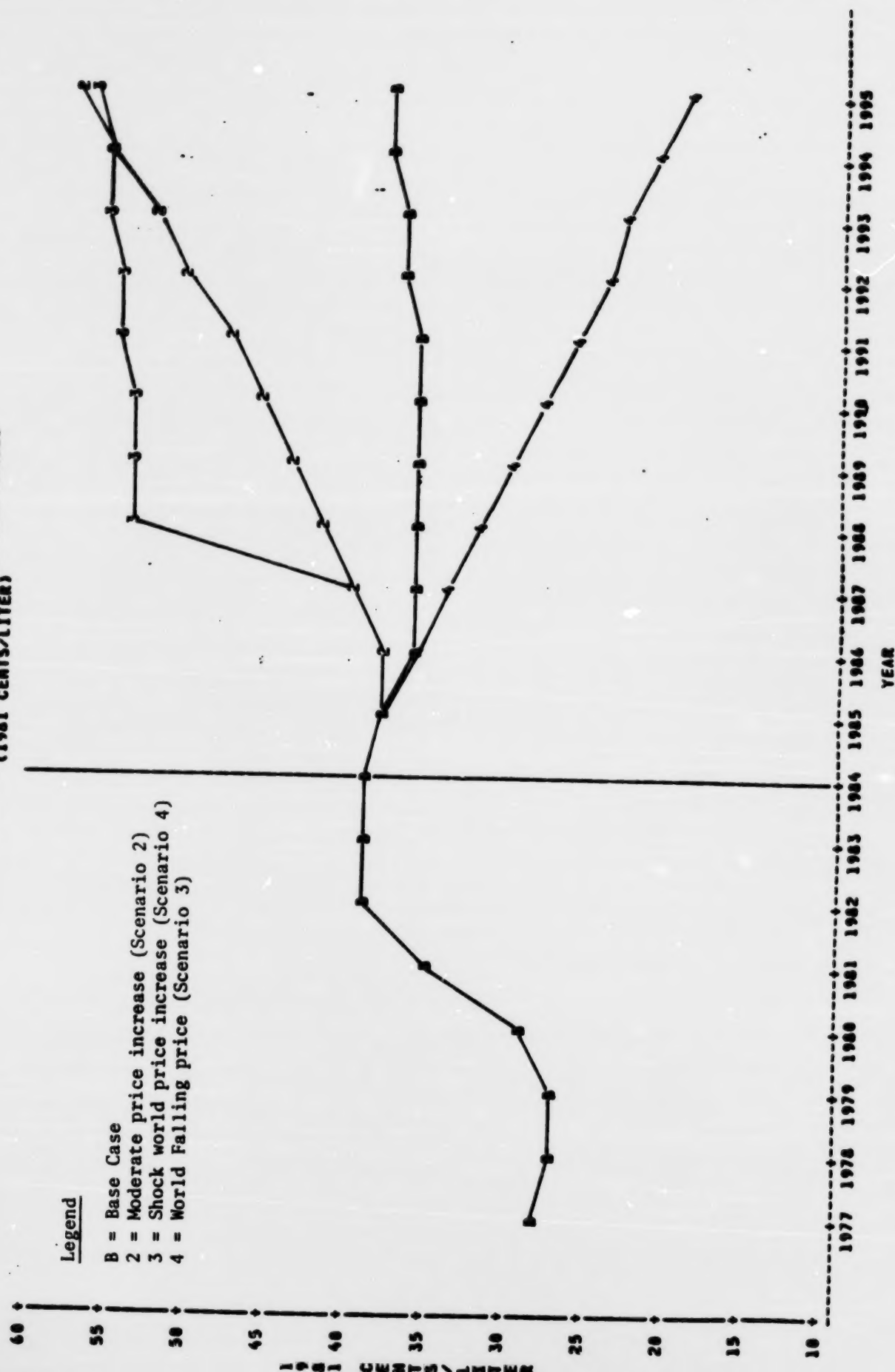
- 4) The Price Shock Case, where both U.S. and Canadian fuel prices have a step increase in 1988, so that the prices in the 1988-1995 period remain at 50 percent above the equivalent price in the Base Case in every year after 1988.
- 5) The Controlled Price Case, where Canadian prices are controlled to stay constant in real terms whereas U.S. prices decline as in Case 3.
- 6) A Worst Case Scenario, where fuel prices decline in both the U.S. and Canada as in Case 3, CAFE regulations are relaxed in the U.S. and all technological improvements are suspended beyond 1988 (i.e., beyond those in an advanced planning stage).

In all cases, it was assumed that Canada would impose the current U.S. emission standards in 1988, and CAFE requirements would be enforced in the U.S. (except in Scenario 6). The fuel price paths in Canada and the U.S. are shown in Figure 1-1 and 1-2, in each country's respective currency.

The methodology used to provide forecasts under each of the six scenarios has been developed by EEA over the last 5 years and has been subjected to extensive scrutiny by the auto manufacturers in the U.S. The manufacturers' approval of the methodology provides a degree of confidence in the forecasts, and we have described the methodology in Section 2 of this report. In brief, the methodology splits the problem of fuel economy forecasting into two areas: determination of manufacturer technology introduction and determination of consumer response.

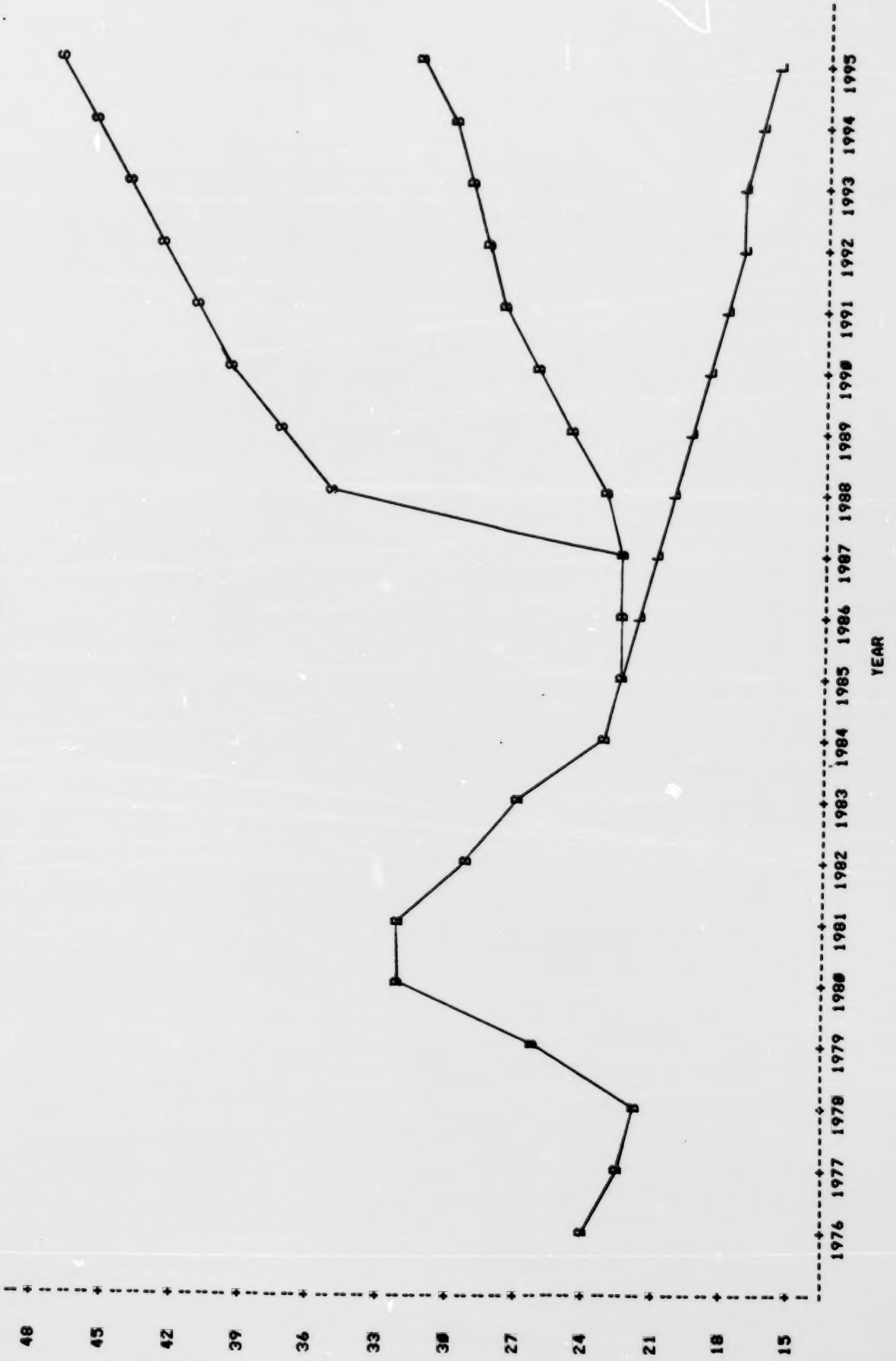
Since the Japanese automanufacturers compete primarily in the small car classes and have relatively high fuel efficiency, and the European manufacturers (with the exception of VW) has limited niche markets, this analysis deals only with the four Canadian domestic manufacturers--AMC, Chrysler, Ford and GM--and their fuel economy is forecast under the alternative scenarios. The influence of the Japanese and European manufacturers is considered only in our analysis of policy options.

FIGURE 1-1
 ALTERNATIVE PROJECTIONS OF CANADIAN FUEL PRICES
 (1981 CENTS/LITER)



U.S. FUEL PUMP PRICE SCENARIOS
(1981 CENTS/LITER)

PLOT OF BASE*YEAR SYMBOL USED IS B
PLOT OF SHOCK*YEAR SYMBOL USED IS S
PLOT OF LOW*YEAR SYMBOL USED IS L



Improvements to vehicle technology are expected to be the single most important factor in the forecast of fuel economy. Because of the long lead time between technology conceptualization and its introduction in the marketplace, there is a wealth of information on the technologies that are available for introduction in the 1985 to 1995 time frame. A detailed description of available technologies is provided in Section 3 of the report. These technologies are the key inputs to our model, called the Technology/Cost Segment Model (TCSM) that is utilized to forecast fuel economy. The TCSM is particularly relevant to this analysis as it forecasts fuel economy by manufacturer and size class given a scenario of U.S. and Canadian fuel prices and data concerning consumer preference for performance as a function of fuel price. It should be noted that current (and, potentially, in the future) voluntary standards require each manufacturer to attain the standard. Thus, the forecast must be specific to each manufacturer; this is readily accomplished with the aid of the TCSM.

Section 4 provides the detailed forecasts of fuel consumption at the manufacturer/size class level under each scenario. (Readers interested in the technological improvements associated with a given level of fuel economy will find a more detailed listing in Appendix A.) Forecasts of Corporate Average Fuel Consumption (CAFC) require knowledge of the mix of size classes purchased. EEA has developed non-linear econometric equations that calculate the mix of size classes as a function of fuel price and real disposable per capita income. Our methodology and forecasts of size class mix are provided in Section 5.

Section 6 integrates the forecasts in Sections 4 and 5 to derive the CAFC numbers under different scenarios. These CAFC forecasts under the six scenarios form the basis of the discussions of policy options that were developed by EEA in consultation with EMR staff. The influence of

five different policies ranging from a fuel tax to the lifting of voluntary restraints on Japanese automobiles is examined. These discussions are expected to provide guidance to Canadian policy makers on the direction and stringency of future policies aimed at reducing automotive fuel consumption.



2. METHODOLOGY

2.1 INTRODUCTION

The evaluation of policy initiatives to influence future fuel economy in Canada requires a detailed understanding of the factors affecting the fuel economy of the new car fleet. Broadly speaking, manufacturers have two options to improve fuel economy: 1) improve the technology of future models; and 2) sell smaller vehicles. Clearly, the first option is dependent on available technology to improve fuel economy, and the second option is influenced by consumer preferences for small vs. large vehicles. Both these options are influenced by other external factors such as fuel price, consumer preferences (for other vehicle attributes in addition to size), emission regulations, competitive forces, etc. Even in the absence of any regulations, it appears likely that manufacturers will introduce new technologies and improve fuel economy in response to these external factors. Accordingly, the development of policy initiatives must be based on relatively accurate forecasts on fuel economy for several scenarios that bound the range of variation of these external factors.

In order to understand the derivation of the fuel economy forecasts, it is useful to have a detailed understanding of the EEA methodology used to forecast fuel economy. The methodology is incorporated into a model, developed for the U.S. Department of Energy, called the Technology/Cost Segment Model or TCSM. The TCSM has the ability to capture a number of real-world engineering and market constraints to provide a realistic representation of the automotive market. The methodology and operation of the TCSM is detailed in Section 2.2. Section 2.3 describes the modification of the TCSM to enable it to model fuel economy in Canada. This section also presents the calculations used for the derivation of

fuel economy in the 1985-1995 time frame in the absence of any new governmental intervention.

2.2 DESCRIPTION OF THE FORECASTING METHODOLOGY

Fuel economy forecasting requires analysis in each of these three areas:

- Vehicle technology
- Manufacturer behavior
- Consumer response

The methodology, described below, accounts for most of the issues in the three areas and is incorporated in the TCSM.

2.2.1 Vehicle Technology

Technological improvements to automobiles have the potential to be the single largest cause of increased fuel economy in the future. The first step in forecasting changes in vehicle technology is to identify the technological improvements that can provide gains in fuel economy for future vehicles and their applicability to different classes of vehicles. This aspect of forecasting has been widely studied since the first oil crisis in 1973 and new technological research and development is extensively reported in the trade press. Improvements in each of the generic categories of technology (such as weight reduction, drag reduction, transmission improvements, and engine improvements) have been and are being researched. Due to the long lead time between technology conceptualization and product introduction, there is a general consensus that new concepts which can be introduced over the next 10 years have already been identified. As a result, this aspect of forecasting is also probably the best defined area in comparison to the other aspects of technological forecasting. EEA has compiled detailed lists of technologies available for future introduction in the U.S., and their application to Canada is discussed in Section 2.3.

The second step is to define the fuel economy benefit and first cost increase associated with the use of a particular technology. Data for estimating the fuel economy benefit is obtained from experimental and pre-production vehicles or from engineering analysis of technology potential. At this point, it is necessary to understand the scope and limitations of the data from which fuel economy estimates are made. For example, both material substitution and drag reduction are not "technologies" that have unique fuel economy benefits and costs, but are dependent on the actual materials utilized or the degree to which aerodynamics is utilized in styling. Costs and benefits must be linked to well defined improvements - in the case of the above examples, to the actual drag coefficient attained or to the extent and type of the material used. It is also important to distinguish between technology cost to the manufacturer and price to the consumer. Confusion between these values are often responsible for widely differing estimates of technology cost/benefit tradeoffs. Our analysis treats the issue from the consumer's perspective and hence utilizes price estimates. Recent studies conducted by Environment Canada have revealed no significant, consistent differences in U.S. versus Canadian pricing historically and we have assumed that this trend will continue.

Even after individual technology fuel economy gains are defined, predictions of the cumulative benefit from adding the individual gains of each technology can overstate cumulative gains considerably as they fail to account for technology synergy and non-additivity. Obvious examples of non-additivity are electronic ignition control with diesel engines or manual transmissions with torque converter lock-up clutches, but even these can be overlooked in forecasts where different technologies are phased in over time. Accounting for technology synergy is much more difficult and requires an engineering analysis to avoid double counting of benefits. For example, both overdrive transmissions and cylinder cut-off systems reduce pumping work and it is clear that adoption of both improvements will not result in cumulative fuel economy gain -that

is the sum of individual gains. Thus, synergistic effects can be estimated for this case by recognizing the maximum extent to which pumping work influences fuel economy.

The fourth step in technology forecasting is the recognition of technology performance issues. These can include issues such as driveability, maintainability, acceleration, noise and emissions. Many of these issues are difficult to quantify, but even a modest effort towards addressing these constraints can yield valuable results. For example, the turbocharger was publicized in the late 1970's as a widely applicable "fuel economy" technology. Our analysis showed that the turbocharger provided poor low speed boost, was limited in capability by the low octane of U.S. gasoline and could delay catalyst "light-off" because of the increased thermal inertia of the exhaust. This led us to believe that forecasts of high turbocharger penetration were incorrect, and that the market for this technology would be limited to a small segment of performance enthusiasts. Thus, it can be seen that erroneous technology forecasts are easily possible unless a detailed understanding of the engineering constraints on each technology is available.

A detailed description of all the technologies that are expected to be utilized by domestic manufacturers to improve future fuel economy is provided in Section 3 of this report.

2.2.2 Manufacturer Behavior

Since the mere existence of a fuel economy technology does not guarantee its availability, it is necessary to understand manufacturer behavior related to introduction of new vehicle technologies. Technology availability and market penetration are partially determined by manufacturers' ability to introduce and manufacture such technologies. Manufacturers, in turn, face:

- Lead time constraints
- Cash flow constraints
- Competitive constraints

Lead time refers to the time required to translate a particular development concept into a product. Lead time has grown over the past decade from about 3 years to an historic high of 5 years in 1980/81 due to the unprecedented level and extent of technological change to new vehicles that are being introduced now. However, it appears that lead time is heading for a substantial decrease in the future due to a number of reasons. Among these reasons are "derived" engines and vehicles, "flexible" manufacturing systems and external sourcing of major components or vehicle subassemblies. In particular, external sourcing of major components such as diesel engines or transaxles is expected to become more commonplace as the domestic vehicles assume the shape and size of those in Europe and Japan. The decreasing lead time projections are for production-related activities; concept development lead time for new technologies may follow historical trends due to the increased regulatory and product liability burden. However, the reduced production lead time and international sourcing arrangements imply that manufacturers can respond more quickly to shifts in customer model preferences and introduce technology more quickly once technology concept development is complete. EEA's forecasts account for these changes by reducing manufacturer response time to sudden changes in demand in the future and by studying technology availability on an international scale. The issue of Canadian versus U.S. technology introduction lead time is considered more fully in Section 2.3.2.

Cash flow constraints have been cited in several instances as a serious limitation on continued technology introduction. Since a particular year's CAFE is a result of major investments in design, tooling and certification over the previous three years, cumulative sales and earnings for the previous three years were analyzed against a particular year's fuel economy. There appears to be no particular correlation between

these variables and in recent years, the correlation between fuel economy and earnings appear to be negative. This is because earnings slide in response to poor sales, thus forcing major product improvements when manufacturers are least able to afford it. As mentioned previously, international sourcing of new technologies or even complete vehicle side-steps the capital constraint issue, although it may carry a profit penalty. In any event, it appears that although capital constraints can limit individual manufacturer plans in specific model years, they are not of much significance in long-term forecasts (i.e., beyond 1990) as "world car" concepts and international links between manufacturers become commonplace. The complex links between U.S firms and Canadian subsidiaries make cash flow analysis for Canada very difficult. EEA has not addressed cash flow issues as they are not of major concern.

Competitive constraints are closely related to the fact that manufacturers must often make product improvements when they are least able to afford it. Assumptions that technological changes are made only in response to fuel price changes or consumer demand for fuel economy do not account for competition between manufacturers in providing technologically superior and cost-effective products. Manufacturers remain competitive by introducing new products on a continuing basis; a typical domestic model has a product life cycle of four years before a "reskin" and seven to eight years before complete redesign. The market-dictated life cycle may lead to significant gains in fuel economy even when fuel prices are flat, as there are several technologies under development that can easily pay for themselves at current fuel prices, i.e., are cost-effective. This concept of technology cost-effectiveness is addressed in greater detail below.

2.2.3 Consumer Response

The study of consumer response to technology is an art that is both difficult and unreliable. One of the most significant findings of consumer surveys is that most people are simply unaware of most technologies that

are being introduced into new cars. The significance of this finding lies in the fact that consumers do not choose most "technologies" but rather, let the manufacturer make this choice. Clearly, for such technologies the manufacturer's decision to incorporate it into a new vehicle is based on its perception of how the consumer will react to it in terms of the technology's cost, fuel efficiency, and performance. Another finding from consumer response studies is that consumers have no clear perception of the performance characteristics of technologies, and manufacturers' decisions on a technology may be augmented by campaigns to influence customer perception.

In order to forecast technology market penetration, EEA has divided the technologies into two categories - "non-discretionary" and "discretionary". Non-discretionary technologies are defined as those which the customer is generally unaware of, or has limited choice in at the time of purchase. As a rule, the characteristics of these technologies rarely detract from the driveability or acceleration performance of the vehicle and are expected to be cost-beneficial in terms of fuel savings. Thus, depending on the rate of change in fuel price and the level of competition forecasted by manufacturers, these technologies are either adopted across an entire model line or not at all, providing only an "all-or-nothing" choice to the consumer. Such technologies include: weight reduction, drag reduction, downsizing, friction reduction, transmission and engine improvements, and improved electronic control. The availability of "non-discretionary" technologies are subject to manufacturers' specific research and capital constraints. Technology adoption also depends upon the cost-effectiveness to the ultimate purchaser as perceived by the manufacturer. To perform the analysis, we have developed a model of the manufacturers' decisions on the adoption of such technologies across specific car lines. (The number of car lines affected by the decision is determined through a study of car life cycle and manufacturer tooling constraints).

In the analysis, the decision to adopt a technology is made if the incremental consumer price of the technology is lower than the discounted value of fuel savings as a result of technology adoption. Fuel savings are calculated over the number of miles driven during four years, typical of average new vehicle ownership. The cost of fuel saved is discounted back to the time of purchase, using a discount rate of 10 percent (real). Thus, a technology is less likely to be adopted at higher fuel economy levels due to the inverse relation between fuel consumption and fuel economy. This simple model of manufacturers' decisions to adopt technology has proved effective in the past, with some modification. Since new technologies must be produced in volume to pay for the research and tooling costs, it is unlikely that technology introduction will be geared to the Canadian market alone, but rather to the entire North American market.

Discretionary technologies are those that have strong effects on vehicle performance, maintainability and/or type of fuel used. Such technologies are offered as options to other technologies and the actual market penetration is subject only to customer preference unless its availability is supply-limited. Since such technologies are purchased for more than their fuel economy, it would be unrealistic to project market penetration based on a simplistic model of cost-benefit to the consumer. These technologies relate to the use of alternative fuels--diesel engines, electric cars, LPG/LNG vehicles, gas turbine engines--or those that affect performance strongly--e.g., turbochargers or similar power boosting technologies. Market penetration for these technologies should be established using the latest information on consumer trends, industry consensus forecasts, and estimates of the upper limits of technology penetration. However, these estimates must be reviewed periodically to track changing consumer attitudes towards new technology. The volatile nature of the results of such surveys can be best illustrated by the rapidly changing forecasts of diesel engine penetration over the past two years. Our approach to estimating discretionary technology penetration for Canada is described in Section 2.3.3.

Consumer preference for different size classes of vehicles influence the mix shift and hence the fleet fuel economy. The current swing towards larger cars has caused consternation among forecasters with regard to the accuracy of earlier fuel economy forecasts, and has also been responsible for some pessimistic forecasts of increased fuel demand. The choice of size class mix is best modeled by a combination of subjective judgements and econometric equations characterizing the mix as a function of economic variables such as period income, fuel price, and cost-per-mile. EEA's approach to estimating size class mix in Canada is described in Section 5 of this report.

2.2.4 The Technology/Cost Segment Model

The technological manufacturer behavior and consumer choice issues discussed are treated comprehensively in a model developed by EEA called the Technology/Cost Segment Model (TCSM). The model is a detailed accounting structure that calculates fuel economy benefits under the appropriate engineering and market penetration constraints. As shown in simplified form in the flow chart in Figure 2-1, the primary components of the model are:

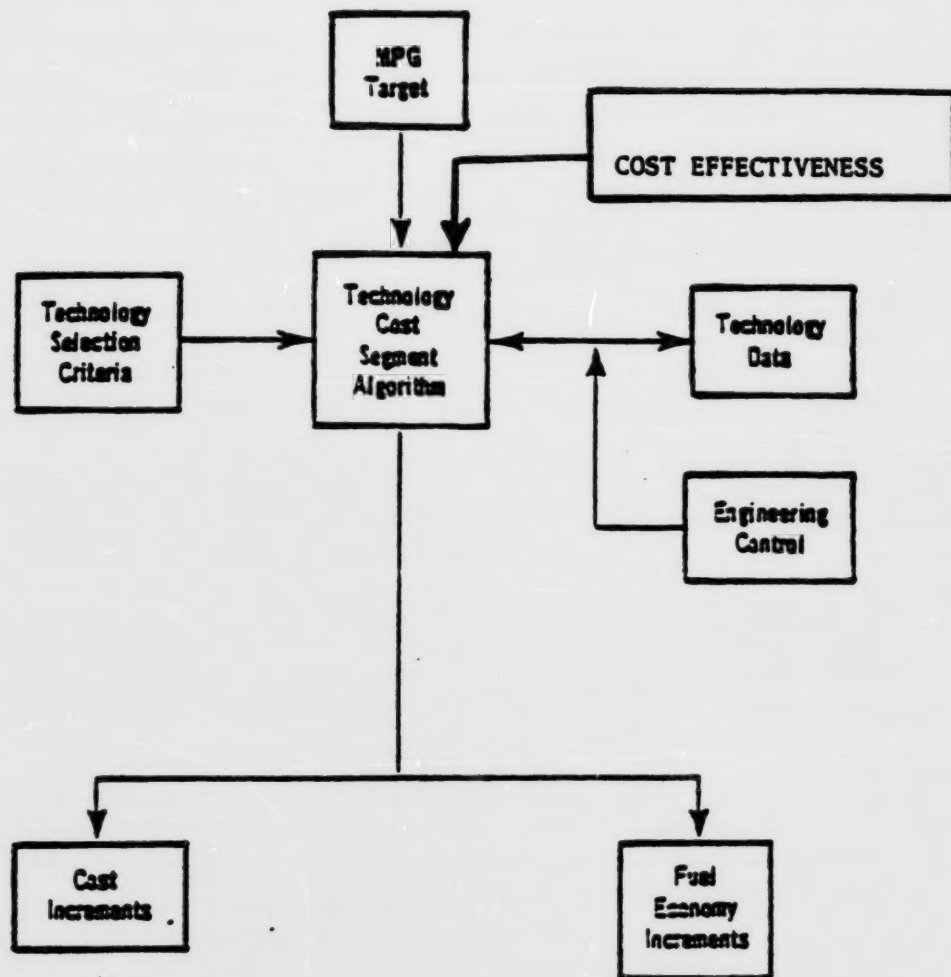
- Technology data
- Engineering control
- Technology selection criteria
- Technology/Cost segment algorithm

To perform its analysis, TCSM employs manufacturer and size class specific data as increments from a fixed base year value of technology, cost and fuel economy. Benefits are specified in terms of percentage gains in fuel economy; costs are specified as increments of consumer price in constant 1979 dollars.

Technology data are organized into a series of matrices called cost matrices that incorporate information on incremental price and fuel economy, the earliest date at which a manufacturer can introduce a given technology,

FIGURE 2-1

SYSTEM FLOWCHART TECHNOLOGY/COST SEGMENT MODEL



production constraints that can limit both minimum and maximum levels of penetration and a series of notes that contain information on engineering control.

Engineering Control is required primarily to account for technology non-additivity and synergy, and also to portray manufacturer behavior regarding early introduction of specialized technologies or specific constraints to market penetration as a result of the desirability of simultaneously introducing several technologies. In the model, this control is excessized by a series of subroutines, one for each technology that is affected by such considerations.

Technology Selection Criteria are used to specify the optimal order of technology selection among the range of technologies available in a particular year to improve fuel economy. The model uses an order vector to rank technologies on the combined basis of availability, relative cost-effectiveness to the manufacturer and engineering applicability. The order vector is also used to force introduction of "discretionary" technologies, such as turbochargers and diesels, that cannot be ranked by conventional criteria. This selection method is flexible and can be used to conduct sensitivity analyses by eliminating certain technologies for use to simulate specific situations such as stringent emissions regulations.

The Technology/Cost Segment Algorithm is the methodology that scans the data and selects technologies for use to achieve increased fuel economy. Two algorithms are used--one in which available technologies are adopted until a specific target is achieved and a second which adopts technologies based on Cost/Benefit to the consumer. The "target-meeting" algorithm is used to demonstrate compliance with regulatory requirements, while the "cost-benefit" algorithm provides a model of manufacturer behavior under free-market conditions. In particular, the Cost-Benefit Algorithm distinguishes between "discretionary" and "non-discretionary" technologies,

and compares the discounted value of fuel savings against technology first cost to select a particular "non-discretionary" technology.

"Discretionary" technologies are adopted to levels specified by exogenous inputs to the model. Obviously, the model requires fuel price projections as an input, as well as the discount rate and payback period.

Given a specific payback period and discount rate, the model then selects all available "non-discretionary" technologies that are cost-effective in terms of fuel savings exceeding the first cost. Discretionary technologies such as diesels and turbochargers are adopted on the basis of externally specified inputs limiting their market penetration. The consumer choice of size classes and of engine options is difficult to model accurately, and econometric models calibrated on past experience have failed to anticipate changes in consumer tastes and preference during periods of rapidly escalating fuel prices. As a result, EEA has tailored the method used for the forecast to the scenario and in some instances, to the client. Our approach to the problem of market penetration does not rely simply on a single econometric equation but, instead, attempts to integrate the opinion of the auto manufacturers and data from surveys to prevent unrealistic predictions from equations calibrated on historical data. Our specific approach to this problem is described below in Section 2.3.3.

2.3 MODIFICATIONS TO THE TCSM/PROJECTIONS OF CANADIAN FUEL ECONOMY

The U.S. TCSM was modified to represent Canadian conditions and then used to project Canadian fuel economy in the absence of any new government initiatives (as well as continuation of existing initiatives without any changes). As discussed in Section 2.2 the TCSM needs exogenous inputs of "discretionary" technology penetration and size class mix to forecast a manufacturer and fleet average fuel economy. Modifications to the TCSM and the methodology used to derive the "discretionary" technology forecast and size class mix are detailed below.

2.3.1 Modifications to the TCSM

The TCSM utilizes a series of data matrices, called cost matrices, where all relevant information on technology availability, cost, fuel economy gain, market penetration constraints, and interaction with other technologies are organized. These cost matrices contain information pertinent to each model for a particular size class and manufacturer, for all domestic (U.S.) manufacturers. Although the manufacturers and models in Canada are nearly identical to those in the U.S., the TCSM cost matrices contain numerous implicit variables that are accurate for the U.S. market only. In order to "Canadianize" the TCSM, each variable was examined and revised to account for differences between the U.S. and Canada. A comprehensive, but not exhaustive, list of these variables are:

- **Baseline.** The TCSM projects technology adoption from a 1978 baseline of technology, cost and fuel economy by manufacturer/size class. The baseline values of these variables were revised to incorporate actual 1978 fuel economy information for Canada.
- **Technology Mix.** Each cost matrix assumes certain values for the mix of non-additive technologies and powertrain option mix. For example, the Ford "small" size class is assumed to have a 55/45 mix of automatic to manual transmissions and technology improvements for each transmission type are weighted by this mix. EEA examined the Canadian mix of technologies by size class and revised the necessary variables based on information provided by EMR.
- **Market Penetration Constraints.** Some technologies in the U.S. market are constrained by limited availability and tooling constraints peculiar to the U.S. Since the Canadian market is much smaller, such constraints may not apply, unless the auto manufacturers "ration" technology to the Canadian market if they are unable to meet demand in the U.S. EEA has found that these constraints apply mainly for captive imports that are restricted due to Canadian/Japanese agreements.
- **Technology Availability.** The assumption that U.S. technology availability is mirrored in the Canadian market is not true for a number of "add-on" technologies, especially those that are related to emission control. For example, fuel injection and knock limiters become much more attractive options at more stringent emissions standards which require using a computer for emission control. Historical patterns in technology availability differences were evaluated in the context of

other requirements (see below) to quantify the extent and nature of these differences. The "scenario" specified by EMR requires that Canada adopt U.S. standards for emissions in 1987/88.

- **Regulatory Requirements.** A number of improvements are forced through regulations--fuel economy, emissions and safety--that differ between the U.S. and Canada. The TCSM was configured for certain implicit assumptions about the regulatory scenarios for the U.S. Since Canadian emissions and safety regulations differ from U.S. requirements, we adjusted technology introduction schedules to match the expected 1987/88 Canadian emission standards.
- **Market Strategy.** The TCSM contains certain implicit assumptions about model offerings by manufacturer and size class. Although, in most instances, there are no differences between the U.S. and Canada, certain specific models are unique to one market (e.g., Pontiac T1000, Chevrolet Sprint). Accounting for such differences involved adjusting introduction dates and maximum technology penetration limits within the cost matrix as well as understanding potential future differences in marketing strategy between the U.S. and Canada. Future differences were isolated to three different models for Canada.

The analysis of each of these variables resulted in a large number of changes within the TCSM that were required to "Canadianize" the model and make it suitable for predicting Canadian fuel economy.

2.3.2 Fuel Economy Forecasts by Size Class/Manufacturer

The Canadian TCSM can be readily used to predict fuel economy for each individual size class and manufacturer for the Canadian domestic manufacturers if one assumes that the selection criteria remain constant, and that information on "discretionary" technology penetration is available. The "non-discretionary" technology selection criteria are described here, whereas the "discretionary" technology penetration forecasts are addressed in the next subsection.

In the TCSM, the selection of non-discretionary technologies is based on the incremental price of new technology being lower than the discounted fuel savings over the typical period of new car ownership. We have used

a discount rate of 10 percent, a payback period of four years and a typical four-year vintage travel distribution for the U.S. to represent the variables used to evaluate the introduction of non-discretionary technology. These values are characteristic of U.S. conditions. We have found little evidence of data to suggest the need for different values for Canada.

Since the Canadian market is small in comparison to the U.S. market, it seems likely that major technology decisions - primarily those involving a complete redesign of the car - are likely to be based on U.S. conditions and the resulting vehicles sold in Canada. On the other hand, many smaller or "add-on" technologies ranging from electronic engine control to torque converter lock-up clutches can be incorporated into Canadian cars (as different from U.S. cars) based on Canadian fuel prices, consumer discount rates, and ownership/travel patterns that are uniquely Canadian. This differential technology penetration question was resolved: 1) historically, there is no evidence of differential technology introduction that is not allied to regulatory requirements, and 2) the manufacturers do not believe that such trends may occur in the future, except for very specific limited model lines.

In the Canadian TCSM, "non-discretionary" technologies are divided into two categories: 1) major ones that require large capital investment and sufficient volume such that the decision to incorporate the technology is made based on U.S. conditions; and 2) minor technologies that can be relatively easily added on to (or deleted from) Canadian vehicles primarily due to regulatory differences as opposed to U.S. vehicles. The TCSM utilizes a two-tier fuel price scenario reflecting U.S. and Canadian fuel prices, and a dual decision framework for "major" and "minor" technologies. The decision to adopt a technology is based on cost-effectiveness calculation, a sample of which is shown in Table 2-1.

TABLE 2-1

SAMPLE CALCULATION

- CALCULATIONS SHOWN FOR FUEL PRICES OF 22¢/LITER AND 35¢/LITER (1981 ¢/l)
- ASSUME BASE VEHICLE FUEL CONSUMPTION IS 8.6 l/100 km
- THE TECHNOLOGY CONSIDERED IS A FOUR SPEED AUTOMATIC PROVIDING A 10 PERCENT BENEFIT IN FUEL CONSUMPTION OVER A THREE-SPEED AUTOMATIC AT AN INCREMENTAL COST OF U.S. \$ 150 (1981 \$)

$$FC_A = 8.60/(1+0.1) = 7.82$$

$$S = 0.22 \frac{(8.60-7.82) \times 1.606}{100}$$

$$\times \sum \frac{14,800}{1.1^{0.5}} + \frac{13,500}{1.1^{1.5}} + \frac{11,300}{1.1^{2.5}} + \frac{10,000}{1.1^{3.5}}$$

$$= \$116.20$$

AT 35¢/LITER

$$S = \$184.87$$

IN THE FIRST CASE THE TECHNOLOGY IS NOT COST-EFFECTIVE AND IS NOT ADOPTED, WHILE IN THE SECOND, IT IS ADOPTED

Once modified, the TCSM predicts vehicle fuel economy, cost and technology in Canada based on:

- A U.S. fuel price path
- A Canadian fuel price path
- Inputs for discretionary technology market penetration

2.3.3 Evaluation of Discretionary Technology Market Penetration

A central concept in evaluating the impact of technology market penetration of fuel economy is the distinction between discretionary and non-discretionary technologies. Non-discretionary technologies are adopted when a manufacturer perceives that the benefits, in terms of discounted fuel savings over a specific "payback" period, exceed the incremental purchase price resulting from technology adoption. Consumers, however, choose certain technologies based on perceptions and preferences that cannot be defined by a simple cost/benefit analysis such as that used in the TCSM. These technologies include: engine size (and cylinder configuration), diesel engines, and turbocharging, and are termed discretionary.

As has been demonstrated by recent history, the market penetration of a discretionary technology such as the diesel engine cannot be governed only by expectations concerning future fuel price increases. Other factors such as the diesel fuel price to gasoline price differential and consumer concerns about diesel engine maintenance, performance and reliability also are important factors to consider. However, they are evaluated outside of the cost-benefit framework of the TCSM.

EEA used the historical data on diesel sales as the basis for the development of forecasts. Our previous experience has shown that there is no single "perfect" methodology that will give accurate results in the projection of discretionary technologies such as the diesel engine. Econometric frameworks often model diesel sales by size class as a function of disposable income, fuel cost per mile and the incremental

cost of diesel engines. However, these models can result in very inaccurate projections since the historical data base on diesel car sales covers only a very limited time period (essentially 1978-present). On the other hand, forecasts of diesel penetration which are based on the potential applicability and cost-effectiveness of diesel engines to different categories of the driving public (segmented by a distribution of cumulative miles driven) ignore the subjective elements of consumer perceptions of diesel performance, reliability, etc. Finally, a methodology which relies on industry consensus forecasts also can be hazardous. This can be no better demonstrated than by the fact that in 1981, the U.S. automobile industry expected diesel penetration in the U.S. to be in the range of 15-20 percent by 1985. Current U.S. diesel penetration in 1984 has barely reached 1.5 percent, and is only slightly higher in Canada.

Given the advantages and disadvantages of the range of methodologies available to forecast discretionary technology market penetration, EEA has used an "eclectic" approach. We have utilized econometric models similar to the the Wharton Auto Model which have forecasted diesel market share as a function of macroeconomic variables, technology cost, and fuel prices. We also have developed estimates of diesel engine sales which are based on analyses of potential market applicability. Through the use of each of these approaches, in addition to our contacts in the automobile industry, EEA arrived at a consensus forecast of diesel engine market penetration by size class and manufacturer for Canada, for each fuel price scenario analyzed.

Although the above discussion has focused largely on diesels, EEA has used similar approaches in developing forecasts for the other visible technologies--engine size mix and turbocharging. In general, for three of the four price scenarios analyzed, "discretionary" technology penetration is not a major factor in determining fuel economy.

2.3.4 Forecast of Size Class Mix By Manufacturer

The TCSM does not forecast the mix of new car sales by size class and by manufacturer. The distribution of sales by size class and by manufacturer is influenced by much more than simple cost/benefit considerations. Factors such as customer brand loyalty, trends in consumer demographics, consumer concerns regarding safety, performance, etc., and manufacturer plans regarding the introduction of models in "new" size classes (i.e., the city-car) are also important influences on size class mix. However, many of these factors are subjective and difficult to quantify.

In the development of forecasts of size class shares by manufacturer, EEA used a number of alternative approaches. These include:

- Analysis and extrapolation of historical trends
- Evaluation of manufacturer production and tooling plans
- Econometric equations which predict market share
- Industry consensus forecasts

Historical data on car sales and production by model in Canada were aggregated to estimate recent trends in sales by size class and manufacturer. One approach to develop forecasts was based on utilizing econometric equations to best fit the historical trends. Since this method does not account for the planned introduction of phasing out of new models in a given size class, it was supplemented with a detailed assessment of available data on manufacturer tooling plans and lead time constraints. For example, city-car market share could not be based on historical trend analysis, for no city-cars have been marketed in Canada to date (except for a Japanese model, the Nissan Micra, only recently introduced). However, knowledge of the manufacturer tooling plans and product introduction dates for city-cars provides an indication of the potential growth in that market segment. Our forecasts of size class mix by manufacturers are more fully described in Section 5.



3. AUTOMOTIVE TECHNOLOGIES TO IMPROVE FUEL ECONOMY

3.1 INTRODUCTION

The development of new technologies to achieve improved fuel economy in future automobiles involves the design and manufacture of new, more efficient engine and drivetrain components, reduction in weight, reduced vehicle size and the substitution of light-weight materials, and improved mechanical performance through the optimization of vehicle design. There are numerous constraints to the introduction and combination of technologies in new vehicles. They vary by manufacturer but include: first costs, fuel economy gains, research and development status, capital availability, consumer tastes, lead time considerations, and Federal and state regulations. All of these constraints will influence the introduction of future new vehicle technologies and their related fuel economy.

This section describes the range of technologies that are being or will be available to improve fuel economy in the 1980 to 2000 time frame. While the availability of a technology does not imply that it will be introduced, it guarantees that, under appropriate circumstances of market demand or regulatory pressure, the auto manufacturers can introduce the technology. EEA has grouped the range of available technologies under eight generic categories. Four of these are directly related to the engine and four are related to the drivetrain or body. Within each generic category numerous "technologies" are available in specific time frames. We have categorized available technologies in each of four time frames: 1980-1984, 1985-1989, 1990-1994 and 1995+. This classification gives an indication of when a technology can be broadly introduced into the fleet, but individual models (usually in the luxury or sports class) may offer limited introduction of any technology a few years before it is widely available.

For each technology, we have provided an engineering description of the method of operation and the effect on vehicle performance, fuel economy, applicability, price and emissions (for engine technologies). The range of technologies described is large and, for major improvements to engines, the descriptions are lengthy and detailed, whereas the descriptions for non-major improvements are limited to one or two paragraphs. To the extent possible, the (lack of) synergism between technologies is also described. The current research or production status for all technologies is presented. All references to fuel economy in this section are based on EPA composite cycle values, a 55/45 harmonic weighting of city and highway mpg values. All references to cost and incremental changes for future technologies represent consumer price estimates in 1981 U.S. dollars (the retail price equivalent). It must be noted that actual pricing will depend on market conditions--e.g., manufacturers may price certain technologies or vehicles under or over the prices estimated here to stimulate or control sales. The price impact derived in this report can be considered as averages that would prevail under competitive market conditions.

An overview of all technologies and the time frames in which they will become widely available for introduction is shown in Tables 3-1 and 3-2 for engine related and body/drivetrain technologies, respectively. In general, all technologies within a generic category are described together. The only exceptions are the lean-burn and gas turbine/Stirling engines. Each of the following subsections covers one generic category with separate subsections for lean-burn and gas turbine/Stirling engines.

3.2 IMPROVEMENTS TO SPARK IGNITION ENGINES 1980-1995

3.2.1 Engineering Description

Although the spark-ignition engine has been in existence for over 70 years a variety of new options to improve fuel economy are now in production or are being planned for introduction before 1990. They include:

TABLE 3-1
ENGINE RELATED TECHNOLOGIES

Time-Frame	S.I. Engines	Alternative Engines	Power Boosting	Electronic Control
1980-1985	- High swirl combustion chamber design - Overhead cam (OHC) 4-cylinder engines - Internal friction reduction	- Diesel engine (I.D.I.)	- Turbocharged diesel engine - Turbocharged gasoline engine	- Throttle-body fuel injection - Electronic spark timing - Idle speed control
1985-1990	- Roller cam followers - Advanced piston and ring design for reduced friction - OHC V-6	- Turbocharged diesel with ceramic combustion chamber	- Vane-type blowers (gasoline engines) - Ceramic turbochargers	- Knock limiters - Multi-point fuel injection - Deceleration fuel shutoff - Shift indicators - Transmission control
1990-1995	- 4 valves per cylinder system - Intake valve control - Lean-burn engines	- Direct-injection (DI) diesel - Uncooled (adiabatic) DI diesel with turbocharging	- Comprex blowers (diesels)	- Engine stop/start - Lean-burn control and "lean" sensors - Diesel fuel injection (for D.I.)
1995+	- Direct injection stratified charge	- Gas-turbine/Stirling		

TABLE 3-2
BODY/DRIVETRAIN TECHNOLOGIES

Time- Frame	Transmission	Weight Reduction	Drag Reduction	Other
1980- 1985	- Manual overdrive	- Front-wheel drive for small cars	- C_d reduced from 0.46/0.5 to 0.36/0.4	- Electric fan
	- Automatic overdrive for rear-wheel drive cars	- Downsizing		- Radial tires
	- Torque converter lock-up	- Unit body structure		- Slippery oils
		- High strength light alloy steel (HSLA)		- Improved water and power steering pump
1985- 1990	- Automatic overdrive transaxle	- RRIM components	- C_d reduced from 0.36/0.4 to 0.32/0.35	- Low profile radials
	- Shift point optimization	- High use of HSLA		- Two-speed accessory drives
		- SMC bodies		- Advanced A/C compressor
		- Front-wheel drive for large cars		
1990- 1995	- Continuously variable transmission (CVT) for small cars	- Aluminum components	- C_d reduced from 0.32/0.35 to 0.28/0.31	- Injection molded tires
		- Graphite components		- Synthetic lubricants
				- Electric power steering
1995+		- Advanced composites	- C_d of 0.2/0.25	- Braking energy storage

- Variable displacement engines
- Engine downsizing through increased specific output
- Internal friction reduction
- Compression ratio increases to 9.2 9.5 CR
- Multi-valve systems and intake valve control.

Variable displacement engines of different types have been under consideration for decades, but the only type that has proven viable is one in which the number of operating cylinders is varied by deactivating the valves. Pumping losses associated with the airflow moving past the throttle plate are substantial at light loads. By reducing the number of cylinders in operation, inlet manifold vacuum is reduced and the operational cylinders function at higher relative loads. This reduces pumping losses and increases combustion efficiency, contributing to an increase in fuel economy.

Many domestic engines have been of low specific output (hp/cu. in.) because of the restrictive effect of inlet and exhaust manifolds, valve train limitations, carburetor limitations, and combustion chamber design. In the past, improvements in these design variables were not cost-effective and increases in power were obtained by increasing engine size. New engines now feature less restrictive intake manifolds and exhaust manifolds. The use of an overhead camshaft reduces valve train inertia, allowing the valves to stay open longer, and thus improves engine breathing. Combustion chamber designs have been modified from the traditional "wedgehead" to the "hemispherical" or "open" designs that allow faster flame travel and reduced knock sensitivity. The increased output of such engines is translated into a fuel economy advantage by substituting a smaller engine of equal power.

Internal friction reduction is achieved through minimizing friction on contact surfaces, improved piston designs and reduction of valve train energy consumption. For example, the use of roller cam followers reduces

the sliding contact in the valve train, decreasing overall friction. Such design improvements are expected to be gradually phased in as existing engines are updated or new engines are introduced. In particular, roller cam followers are currently being introduced in several engine lines.

Compression ratio (CR) increases in gasoline engines can be implemented without any increases in octane requirement through the use of a high swirl combustion chamber. Increasing compression ratio increases the thermodynamic efficiency of the engine; typically, a one point increase in compression ratio is possible using high-swirl technology.

In the post-1985 time frame, a second round of friction reduction is likely as manufacturers utilize new low friction piston design, low-tension piston rings and better control of piston and bore dimensions. These have become possible partly because of more sophisticated manufacturing systems that can machine the engine block to closer tolerances than previously possible. Engine lines featuring these improvements are expected in conjunction with new manufacturing facilities, such as those for GM's Saturn project.

New valve control technologies are being investigated to reduce pumping losses. At part-throttle, it is more efficient to close the intake valves early rather than to throttle airflow. One method to achieve this is to use an innovative cam design that allows valve timing to change as a function of load. Another method is to use two intake valves per cylinder and shut one valve off at low loads or speeds. An engine using two intake valves and two exhaust valves (4-valve) produces as much as 25 percent greater power than an equivalent displacement 2-valve engine. Hence, a smaller 4-valve engine can be substituted for a 2-valve engine with greater fuel economy benefit.

3.2.2 Application

All of these improvements have been introduced to some extent, depending on manufacturer strategy and downsizing plans. New engine introduction plans are closely related to new car introduction plans, and each improvement is phased in over a period of time across existing engine lines. Cadillac has been the only manufacturer to introduce variable displacement engines--the "V-8-6-4" engine--in 1981. All three domestic manufacturers introduced new engines in 1981 employing friction reduction, open combustion chambers, and overhead camshafts. GM has introduced a high compression V-8 with knock-limiter for Camaro and Firebird cars. Older engines such as the Pontiac 151 CID engine or the Ford 302 V8 have been updated with improved intake and exhaust manifolds. Most of today's engines feature design improvements implemented since 1980. In 1985, Toyota introduced a 4-valve 4 cylinder engine with special intake controls on the Corolla.

3.2.3 Performance

Except for the variable displacement engine, most of these improvements are "invisible" to the driver. The variable displacement engine proved to be jerky and troublesome in its initial appearance in the Cadillac and was discontinued but proper operation theoretically should render this improvement to be nearly "invisible". It must be noted that the variable displacement engine is not compatible with overdrive transmission, since both reduced engine speed and decreased number of operational cylinders are not simultaneously possible. Improvements leading to increased specific power (e.g., 4-valve engines) generally improve top-end performance, resulting in better passing acceleration and higher maximum speed without any negative effect on low speed performance. EEA believes that variable displacement engines are unlikely to be reintroduced.

3.2.4 Fuel Economy

The gains in fuel economy due to increases in specific power or to friction reduction are difficult to generalize because these factors can vary from engine to engine. In addition, increases in specific power are often used to improve performance rather than fuel economy, in which case no net gain in fuel economy is achieved. Trends in 1980-1985 show that friction reduction will provide an average fuel economy improvement of 4 percent on all new engines.

Variable displacement engines show an 8 to 10 percent increase in fuel economy. High-swirl high compression engines provide a 4 percent gain in fuel economy (assuming a 1 point increase in CR) while roller cam followers provide another 4 percent gain.

The next round of friction reduction through the use of advanced manufacturing techniques is expected to provide an additional 4 percent benefit in fuel economy. Intake valve control can provide on a 8 percent benefit in fuel economy, but the benefits are not additive with those of overdrive transmissions, as both systems reduce pumping work. In conjunction with overdrive transmissions, intake valve control is likely to provide only half the benefit, i.e. 4 percent. An engine using 4-valve combustion chambers with some form of intake control (as with Toyota's system) can provide a 10 percent benefit in fuel economy in comparison to a 2-valve engine of equal power. EEA expects that 4-valve 6 cylinder engines will replace V-8's and 4-valve 4 cylinder engines will replace performance V-6's in this application. Because low-end torque may suffer, axle ratio changes or gear ratio changes may be expected during this conversion to reduce fuel economy benefits to 8 percent.

3.2.5 Cost

Since friction reduction and combustion chamber designs are generally incorporated during engine redesign, the impact of these improvements on

consumer price is difficult, if not impossible, to compute. EEA has considered these costs to belong under costs for "normal product development", while others have ascribed a consumer price of about 70 dollars. In the case where improvements in engine specific power and vehicle weight reduction allow the use of a 4-cylinder instead of a 6-cylinder engine, variable costs are negative. EEA believes that, the net consumer price impact due to these improvements is \$70 if a 4-cylinder of advanced design is substituted for a 4-cylinder engine of older design.

Variable displacement engines have an incremental consumer price of \$150 over a similar conventional engine. The price of increasing compression ratio is essentially zero. (The knock-limiter is priced separately in this report). Roller cam followers are expected to cause a price change of approximately \$10 for a 4-cylinder engine to \$20 for a V-8 engine.

Costs for the intake valve control system are difficult to ascertain. If the system is similar to the valve shutoff mechanism employed in the Cadillac, then the incremental price will be about \$80 for 4-cylinder engine and \$80 for a V-6. Incremental costs for the 4-valve engine are based on V-6's replacing a V-8 and a 4-cylinder replacing a V-6; we estimate that the cost will be \$100 for a 4-cylinder and \$140 for a 6-cylinder engine. These increments will be substantially larger if compared against an equal displacement engine, but then vehicle performance does not remain constant.

3.3 HIGH COMPRESSION/LEAN BURN ENGINES

3.3.1 Engineering Description

There has been considerable interest over the past 5 years in high compression lean burn engines that bridge the gap between diesel and current gasoline engines. There are three basic concepts:

- The high swirl, high compression or "Fireball" type engine
- The direct-injection, stratified charge engine
- Closed-loop high swirl lean combustion

Although it is well known that high compression ratios lead to increased efficiencies, the limiting features are gasoline octane number and knock. These problems are overcome in the first concept by operating at very lean air-fuel ratios (typically 20:1) and using high swirl to promote high flame speed. In the second, the fuel is injected into turbulent air after compression (like a diesel) but is ignited with a spark plug. In both cases, compression ratios of 12:1 to 14:1 are employed with the added fuel economy gains due to the reduced pumping and combustion losses associated with lean burn.

The high compression, high swirl system has been investigated in Europe by Porsche and Michael May, the inventor of the "Fireball" combustion chamber. This chamber was adopted by Jaguar in their V-12 engine for 1982. The "Fireball" concept needs a fuel-injection system to control air fuel ratios at very lean values. It must be noted that current "Fireball" engines have been optimized for the higher European octance number (97) for gasoline, and may need redesign before introduction in the U.S.

The direct-injection stratified charge concept has been investigated by all domestic manufacturers as well as Texaco. The Ford system, called PROCO, was due to reach production in 1983 but was cancelled. Texaco's TCCS system has seen limited operation in fleet use by UPS. In this application the direct-injection of gasoline fuel into the cylinder head requires a sensitive high pressure fuel injection system, which has proved expensive.

The closed loop lean combustion engine operates at very lean requires--A/F ratios of over 20:1--by utilizing an external device to carefully control

swirl, fuel metering and automization. Toyota has recently introduced a 4-cylinder 1.6 liter unit featuring a zirconia sensor that measures lean air-fuel ratio, compiled with a sequential multipoint fuel injection system that delivers highly atomized fuel into the cylinder. A special swirl control valve used at part-throttle provides high swirl and the ability to run very lean. At idle and full-throttle, the engine is calibrated like a normal "rich-burn" engine.

3.3.2 Performance

The "Fireball" concept engine and the Toyota lean-burn engine typically do not offer any performance difference in comparison to fuel-injected, normal compression ratio vehicles. The direct-injection stratified charge requires a highly sophisticated fuel injection pump and up to two spark plugs per cylinder, causing a substantial increase in maintenance costs. Acceleration performance for all three types of engines are essentially similar to current gasoline engines, but lean-burn systems may feel "stretchy" at part-throttle.

3.3.3 Fuel Economy

The Jaguar V-12 "Fireball" engines have achieved a 20 percent gain in fuel economy when converted to lean burn operation. However, lean burn operation is more suited to this large engine, where NO_x emissions are not a problem. For smaller engines operating under U.S. octane restrictions, the "Fireball" type engine should provide a 12 percent increase in fuel economy at a 1 g/mi NO_x standard and up to 15 percent gain in fuel economy at a 2 g/mi NO_x standard. Toyota is offering their 1.5L lean burn engine in Japan and it shows a 15 percent improvement over the equivalent 1.5L featuring three-way catalyst control.

A direct engine stratified charge is expected to provide a 20 percent fuel economy gain at a 1 g/mi NO_x standard and a slightly higher gain at a 2 g/mi NO_x standard, but these figures are based solely on prototype engines.

3.3.4 Cost

The principal costs associated with a "Fireball" type engine are those for designing a new cylinder head and piston. Variable costs for such engines are not very different from conventional s.i. engines, with the exception of the fuel injection system. As a result, cost of a "Fireball" engine is similar to that of today's fuel injected engine. However, it is likely to be priced at some premium over conventional fuel injected engines to overcome the research and tooling cost penalty. We estimate that the incremental price will range from \$80 for a 4-cylinder engine to \$120 for an 8-cylinder engine.

The direct-injection stratified charge engine is expected to be priced at about the same level as a diesel engine, or even slightly higher. (It was rumored that this was the prime reason behind Ford's decision to drop the PROCOT, as fuel economy benefits were not comparable to that provided by a diesel.)

The Toyota lean burn engine features a swirl generator and an advanced lean mixture zirconia sensor. Based on the Japanese experience, EEA estimates a price increment of \$60 for an engine equipped with this system. However, there is some uncertainty whether the Japanese engine can meet the 1.0 g/mi NO_x standard without further modification.

3.4 DIESEL ENGINES

3.4.1 Engineering Description

The diesel engine uses a fundamentally different combustion process than the spark-ignition (gasoline) engine. In the diesel, intake air is heated by compression to a temperature sufficient to ignite the fuel. Diesel fuel is then injected as a spray at very high pressure, with combustion taking place at the air-fuel interface of the spray droplets. (In spark-ignition engines, air and vaporized fuel are pre-mixed, and the homogenous mixture is ignited by a spark).

The diesel inherently is more efficient than spark-ignition engines as a power plant for motor vehicles. First, the diesel has a greater thermodynamic efficiency because it operates at much higher compression ratios than a gasoline engine (22:1 versus 8:1). Second, current diesels are unthrottled and achieve part-load operation by reducing the rate of fuel injection, therefore leaning the air-fuel ratio. In contrast, gasoline engines throttle the intake during part-load operation, incurring pumping losses associated with airflow pass the throttle plate, and maintain approximately constant air-fuel ratios across the operating range. Diesels therefore offer particularly efficient operation during idle and low-load conditions, which are very common in urban driving patterns.

Since the diesel combustion process is controlled by the rate of fueling, performance of the injection system is critical. All of the current passenger car diesels feature a pre-chamber design in which the air and fuel spray are partially mixed and ignited before combustion spreads to the main chamber. This design limits the rapid pressure rise which occurs in a direct-injection diesel (found in medium and heavy-duty trucks), with attendant reductions in noise, vibration, and NO_x emissions. The prechamber design also makes the combustion process less sensitive to the performance of the fuel injection system and allows the use of a less expensive rotary injection pump. However, the lower rate of pressure rise and the additional heat transfer of the prechamber design results in lower specific fuel economy than in the direct injection diesel.

The recent emphasis on fuel efficiency has resulted in considerable growth of the passenger car diesel market. Diesel engines have been available in Mercedes and Peugeot imports for the past two decades, but the high prices of these models have kept market penetration very low. General Motors and Volkswagen first introduced diesels in 1978 to the medium- and low-price segments of the passenger car market. Other manufacturers also have introduced diesels in the non-luxury market. These include Audi and Volvo in 1980/1981 and Isuzu and Datsun in 1981/1982. Currently,

diesel engines account for less than 1.0 percent of the domestic market (including Volkswagen) and 2.0 percent of the import market, down substantially from their peak in 1981.

3.4.2 Performance

Diesel engine performance traditionally has been a deterrent to its widespread acceptance. The principal disadvantages of the diesel compared to gasoline engines are:

- Poor acceleration
- Increased noise and vibration
- Cold start performance
- Exhaust smoke and odor

Performance **advantages** for the diesel include reduced maintenance and better throttle response which eliminates stumbling and hesitation in any weather.

Acceleration performance has been poor because diesels have significantly lower peak power output than gasoline engines of equal size (displacement), due to the higher internal friction of the diesel engine as well as limitations on the diesel combustion process. In particular, smoke production increases at high fueling rates due to incomplete combustion of the injected fuel droplets. The engine design must therefore limit peak power to control smoke to acceptable levels. A diesel engine is also heavier than an equivalent gasoline engine to withstand the higher stresses of the increased compression ratio, with a resulting adverse impact on power/weight ratios.

Diesel performance can be increased by using a larger engine or by turbocharging, although with price and fuel economy penalties. During times of high fuel prices, however, consumers have been willing to accept reductions in traditional performance in return for increased fuel economy,

as exemplified by cars like the Dodge Omni Miser. The typical range of performance, measured as the 0 to 60 mph acceleration time, is shown in Figure 1, where it can be seen that diesels are competitive in performance with typical "fuel economy" or "family" sedan gasoline cars. Alternately, the use of turbocharging can make diesels competitive even at high performance levels.

Although diesels have increased noise and vibration levels, insulation and rubber engine mounts have successfully minimized these problems in current cars so that the average driver cannot differentiate between gasoline and diesel engines. Slow cold start and warm-up performance of diesels has been improved through the use of EGR. GM already has developed a "fast-start" glow plug system that allows the diesel to start in 60 seconds in 0 degree weather. Exhaust smoke and odor are problems that are less readily solved, but it appears that particulate traps (addressed elsewhere in this section) will provide moderate control of both.

3.4.3 Fuel Economy

Although diesels traditionally are thought to be 25 percent more efficient than gasoline engines, comparisons from currently available models show that the fuel economy gain can range from 15 to 55 percent, depending on the type of comparison being made. (Equal engine size, equal performance, or model to model comparisons produce very different results). One problem with comparing diesel to gasoline fuel economy is that diesel and gasoline versions of the same car rarely exhibit similar performance characteristics, while comparisons between different models can reflect manufacturer and drivetrain differences. The limited number of diesel models available also make accurate comparisons difficult.

Current diesels show 35 percent improvement in fuel economy on average, reflecting the performance difference between average gasoline and diesel cars. In a "best-to-best" comparison which (approximately) equalizes

FIGURE 1
PERFORMANCE COMPARISON

<u>Gasoline</u>	<u>0-60 Time (seconds)</u>	<u>Diesel</u>
Sports Cars (Covette, Z-28)	8-	
	10-	
Performance Cars (Camaro, Mustang)	12-	BMW Turbo-Diesels
Average Sedans	14-	Mercedes Turbo-Diesel
Fuel Economy Cars	16-	Volkswagen Diesel
	18-	
	20-	GM, Mercedes Diesels
	22-	Peugeot Diesel

performance, the fuel economy improvement over gasoline engines is 17 percent for a naturally aspirated diesel and 29 percent for a turbocharged diesel.

In addition, diesels have much lower fuel economy shortfall (difference between real-world and EPA fuel economy), than gasoline engines. This difference in shortfall ranges from 6 percent (for low fuel economy cars) to 25 percent for high fuel economy cars. Diesels especially show fuel economy advantages in city traffic, as they use very little fuel during idle, and in comparison to gasoline engines, also use much less fuel during the cold start and warm-up phase. In real world economy, therefore, the diesel can provide up to 50 percent improvements over gasoline engines in an "average-to-average" comparison.

3.4.4 Cost

EEA estimates that under competitive conditions a 4-cylinder diesel would be priced at \$350 over a gasoline engine, and a 8-cylinder at a \$750 premium, with 5- and 6-cylinder engines between those estimates. (Prices in constant 1981 dollars). Future unit cost reduction may be offset by the increases cost of meeting more stringent emission standards. Under today's soft market for diesels, manufacturers offer incentives that provide the diesel as a no cost option.

3.4.5 Environmental Constraints

There has been controversy in recent years over the ability of diesels to meet emission standards for NO_x (1 gm/mi) and particulates (0.2 g/mi) in combination. Recent evidence indicates that most diesels have met the NO_x standard through the use of EGR*. Particulate trap research

*The GM V-8 diesel is an exception. but this engine is schedule to be discontinued.

currently is intensive and many emission control manufacturers (GM, Johnson-Mathey, etc.) have recently shown designs that appear to easily meet the particulate standard at low mileage. Mercedes has introduced a trap for its diesels in California in 1985. The traps also appear to have the additional benefit of even larger reductions in carcinogenic organics and odor causing emissions than reductions in total particulate emissions. While the durability of the traps is still in doubt, a growing body of evidence suggests that traps will be successful in meeting the 0.2 gm/mi particulate standard. Health effects research also is showing much lower risks from particulates than what was previously expected. For these reasons, EEA projects that passenger car diesels will not be subject to environmental constraints in the near future.

3.4.6 Direct-Injection Diesel

As explained previously all of today's passenger car and light truck diesels are of the prechamber type. Conversion to direct injection results in a 15 percent fuel economy benefit over an equal displacement prechamber design. This large benefit has resulted in considerable interest in applying direct-injection to cars and light trucks, and there are several experimental models currently undergoing development. Much of the work is being performed in Europe by AVL, BMW, VW and MAN.

The direct injection diesel has suffered from the problems of increased noise and vibration as well as higher particulate emissions. The key to control of these problems lies in the fuel injection system. The use of electronic control and more advanced injection pumps has resulted in improved potential for the direct injection diesel. The status of current research shows that direct injection diesels are very close to meeting all applicable U.S. emission standards, while noise and vibration levels are competitive with current prechamber engines.

It appears that direct injection diesels can be introduced around 1990 by several foreign manufacturers and, perhaps, by domestic manufacturers in its luxury cars. Other manufacturers may introduce this engine before 1990 under an accelerated schedule, but the conversion to direct injection is more likely to occur in the early 1990's. Current estimates show that the conversion will add \$120 to the price of an existing diesel.

3.4.7 Combustion Chamber Insulation

A significant amount of the heat of combustion in a diesel engine is lost to the walls and coolant. The use of ceramics in the piston crown and combustion chamber walls can prevent this heat loss; such engines are often referred to as "adiabatic" diesels. On these engines, it is theoretically possible to completely eliminate the cooling system, radiator and fan, resulting in significant cost and weight savings. Unfortunately, the increased thermal insulation has the undesirable effect of reducing the volumetric efficiency of the engine and increasing the heat rejected to the exhaust. To compensate for these effects, turbocharging or exhaust waste heat recovery devices are required. Although insulation by itself may not lead to any increase in fuel economy, it is very useful in synergy with turbocharging and waste heat recovery devices.

Since turbocharging and waste heat recovery devices operate at high efficiency only near high speed/high load conditions, "adiabatic" engines are most useful in heavy trucks. Cars and light trucks rarely operate at high speed/high load conditions and the utilization of such devices are not as cost-effective. However, a German firm (Elko) has recently demonstrated an insulated, turbocharged passenger car diesel that utilizes only oil cooling, thus eliminating the coolant and radiator. Fuel economy gains are achieved through the weight reduction afforded and through the increased turbo efficiency due to insulation of the combustion chamber. In addition, the use of ceramics has some favorable

affects on hydrocarbon (HC) emissions as well as engine wear. The price of insulation is difficult to gauge, but may be offset by the reduced costs associated with the elimination or simplification of the cooling system. We estimate that a turbocharged diesel with ceramic components will provide a 5 percent fuel economy gain over a similar metal engine at an added cost of \$50.

3.5 POWER BOOSTING

3.5.1 Turbocharging

3.5.1.1 Engineering Description

Internal combustion engines, both gasoline and diesel, reject 25 to 50 percent of the fuel energy into the exhaust. A turbocharger recovers some of this wasted energy, thereby increasing the power rating of the engine. The turbocharger consists of a turbine placed in the exhaust path which drives a compressor in the intake manifold, compressing incoming air to the engine. The higher pressure of the intake manifold results in more air being forced into the engine, thus generating more power.

The turbocharger can be used to improve performance or fuel economy. Its use as a performance device is obvious. As a fuel economy device, the turbocharger allows the use of a smaller, lighter engine without a performance sacrifice. Smaller engines with turbochargers have lower fuel consumption during idle and cruise conditions than larger, naturally aspirated engines of equal power. Depending on the choice of engine and turbocharger, performance can be traded off against fuel economy.

3.5.1.2 Application

Turbochargers function more effectively with diesel engines than with gasoline engines for two reasons. First, since the turbocharger compresses intake air, its effects on combustion are similar to that of

an engine operating at increased compression ratio. Gasoline engines are compression limited by "knock" and the pressure boost delivered by the turbocharger must be carefully controlled to a low value (5~7 psi) to prevent knock. No such limitation exists for diesel engines, and turbo-charger boost is only a function of engine material limitations. Second, gasoline engines throttle the intake air at part load conditions, whereas diesel engines reduce only the fuel delivered. Intake air throttling renders a turbocharger ineffectual and hence, the turbocharger is utilized only under relatively infrequent wide-open throttle conditions in gasoline engines.

There are a number of problems associated with turbochargers, some of which are a result of natural laws governing the performance of turbines. For example, the complex interrelationship between boost pressure, airflow and turbocharger speed (RPM), results in a turbocharger providing little or no boost at low engine speeds and a very rapid rise in boost at high engine speeds. The conflict between boost and engine speed requires careful matching between turbocharger size and engine RPM to maximize mpg and performance benefits. The turbocharger's performance, cost and fuel economy gains are sensitive to the conflict between boost and engine speed design tradeoffs. The tradeoffs are discussed below, and the performance and fuel economy issues are highlighted.

As manufacturers phase out the large V-8 engines, they have begun offering turbocharged gasoline engines to satisfy customers requiring performance. Both GM and Ford have offered turbocharged engines for over 2 years, and a number of European importers (Audi, Saab, Porsche) have offered them in expensive high performance cars. Turbocharged diesel engines are currently offered by Mercedes, Peugeot and Toyota. Total market penetration of turbocharged engines has been very small (2 percent in 1984). The reasons for the turbochargers limited penetration are considered below.

3.5.1.3 Performance and Fuel Economy

The acceleration characteristics and fuel economy gains are dependent on how the turbocharger is "matched" to the engine. If the turbocharger is sized to provide boost at moderate engine speed (2000 to 3000 RPM) but sacrifice some maximum power at higher engine speeds, the engine will provide good performance in the 40 to 70 mph range. At the very low RPM range (for example, a hard acceleration from a stop sign), the engine behaves like a normally aspirated engine of identical size. After the vehicle exceeds 25 to 30 mph, it behaves like a larger normally aspirated engine. The EPA fuel economy gain is approximately 5 percent over the larger normally aspirated engine of the same power. Mid-range boost offers the best compromise between fuel economy and performance.

If all the boost is concentrated on the high end of the engine RPM range to optimize for maximum power, there is no gain in either performance or EPA economy during normal driving in comparison to a naturally aspirated engine of equal displacement. All the performance improvement is available only for high RPM gear shifting, and the turbocharger appeals to a performance oriented group of buyers. For example, the behavior of the Mustang Turbo at low to moderate engine speeds resembles that of the naturally aspirated engine from which it is derived. Although fuel economy comparison with a V-8 shows a 10 percent gain, there are considerable differences in low speed acceleration between the two. It is clear that for gasoline engines the characteristics of the turbocharger appeal only to those buyers interested in maintaining high performance. For such customers, the turbocharger provides a 10 percent fuel economy benefit over a V-8, albeit at the expense of poor performance over a significant portion of the engine's speed range.

Diesel turbocharging could result in a price impact very similar to that for gasoline engines for modest maximum boost pressures (10~12 psi). At a higher boost pressures, piston cooling requirements and strengthening

of internal engine parts as well as cooling system improvements may raise the price significantly. High boost pressures allow diesels to be competitive in acceleration performance with gasoline engines and the price is illustrative of the cost/performance tradeoff that customers will face in the future. For example, Peugeot has chosen the modest boost path, while BMW has chosen to use high boost to maximize performance. On average, EEA estimates that a turbocharger will provide a 10 percent benefit in fuel economy for diesels.

3.5.1.4 Environmental Constraints

The effect of turbocharging on emissions is dependent on the application. For gasoline engines, turbocharging can increase emissions for two reasons. First, the thermal mass of the turbine wheel in the exhaust delays catalyst warm-up, increasing HC and CO emissions. Second, if a smaller, more highly loaded engine is used (i.e., the turbocharger is used as a fuel economy device), NO_x emissions will increase. If the engine is not more highly loaded (i.e., the turbocharger is used to provide extra performance only), the turbocharger does not affect emissions on the EPA test cycle as there are no "wide open" throttle driving regimes during the test.

For diesel engines, the use of the turbocharger as a combination fuel economy/performance device typically results in decreased HC and particulate emissions due to the extra air available for combustion. NO_x emissions may increase but only by a small percentage (10 percent). Thus, in general the use of turbochargers on diesels result in more favorable emission characteristics.

3.5.2 Other Supercharging Technologies

Although the turbocharger is the most widely used form of supercharger, several other supercharging technologies are being researched. The most important technologies are:

- Comprex
- Roots blowers
- Positive displacement pumps

These technologies are being investigated to eliminate the turbocharger's problems of poor low end torque and difficulty of matching with piston engine requirements.

3.5.2.1 Comprex

Comprex superchargers have been investigated for decades in Europe, principally by Brown-Boveri and MAN. They utilize the pressure pulsations in the exhaust manifold to compress intake air in a rotating device that actually places the intake and exhaust gases in contact with each other. This also results in some mixing of exhaust gases with the intake air. Although the Comprex has worked in certain applications, it has been difficult to control and has provide expensive. EEA is of the opinion that it is likely to be available in the post-1990 time frame.

3.5.2.2 Roots Blowers

Roots blowers have been in use in aircraft engines since World War II and in limited production automobiles (such as Bentley and Mercedes) in the early 1930's. There has been renewed interest in this device recently. For example, Fiat is testing a Roots blower-equipped car. The Roots blower is similar to a gear pump in operation, and consists of two lobe rotors geared together and enclosed in a housing. The rotors are connected to the engine crankshaft via a toothed belt and their rotation provides compression of intake air. Roots blowers are considerably bulkier than turbochargers and require precision castings and pressure seals for proper operation. However, they provide constant boost over much of the engine operating range, except at very low speeds where air leakage past the rotors results in very low boost.

3.5.2.3 Positive Displacement Pumps

Positive displacement pumps are similar to air pumps used in current vehicles for emission control. Bendix has been developing these pumps (vanetype) for use as superchargers. As with Roots blowers, they are bulky and need to be driven off the crankshaft. They are cheaper to produce than Roots blowers and produce somewhat higher low-speed torque. However, their durability characteristics are inferior to Roots blowers.

3.5.2.4 Application

Competition between Roots blowers and vane pumps for the gasoline supercharger market is likely. Since their size increases linearly with engine size, they become much too bulky for use with large engines. In addition, since they are driven off the crankshaft, the drive system becomes too complex to transmit the high power required. For these reasons, EEA believes that superchargers (either Roots or vane-type pumps) will be used primarily in small and compact cars as well as small LDT's. In both categories the application of superchargers will be combined with engine downsizing/axle ratio reduction to provide increases in fuel economy.

Unlike turbochargers, these supercharging technologies are more compatible with engines as diesels have much higher airflow at the same power, requiring greater power input to the supercharger. EEA estimates that superchargers can provide an 8 percent gain in fuel economy for gasoline engines and a 5 percent gain in fuel economy for diesels for constant performance conditions. However, superchargers may be offered as an option to increase performance, and reduce these gains to 5 and 10 percent, respectively. As stated earlier, their application will be restricted to small engines in cars. Consumer prices for the supercharger, are likely to be \$250 to \$300 depending on application. The Roots blower is likely to be more expensive but offers greater durability and quieter operation. Both supercharging technologies can be commercialized by 1990, although the price seems to favor introduction of the vane-pump supercharger.

3.6 ELECTRONIC ENGINE CONTROL

3.6.1 Engineering Description

The use of the microprocessor in cars is expanding rapidly to satisfy the conflicting demands of low exhaust emissions and increased fuel economy. The use of a microprocessor to control the engine and drivetrain allows these functions to be optimized selectively without the rigid constraints imposed by mechanical systems. Various types of controls are being researched or introduced. Those that provide gains in fuel economy are outlined below:

In the 1981-1985 time frame, the electronic controls that have been used are:

- Gasoline fuel injection (throttle body)
- The knock-limiter
- Idle speed control

In the 1985-1990 time frame, controls to be introduced are:

- Multipoint fuel injection
- Deceleration fuel shutoff (gasoline)
- Diesel electronic fuel-injection
- Driving aids to alert the driver to improve fuel economy
- Engine shutoff during idle
- Transmission control

In the post-1990 time frame, EEA expects widespread use of electronic controls for gas turbine and electric vehicles (if they prove successful in the market), but their effects are not considered here.

Fuel injection allows precise metering of fuel through electronic control. There are two types of systems--throttle body injection (TBI) or multipoint. Multipoint systems have been used in European cars to provide high specific power output as a result of elimination of restrictive

carburetors and intake air pre-heaters. Throttle body injection is a simplified system that utilizes one or two injectors replacing the carburetor and mounted ahead of the intake manifold. Throttle body fuel injection achieves a 3 or 4 percent gain in fuel economy over carburetors because it allows more precise control of fuel metering during transients and warm-up. Multipoint fuel injection allows even better control and provides improved acceleration and cold weather performance. This system can provide a 6 or 7 percent gain in fuel economy over a carburetor.

The knock-limiter is an electronic device that senses trace knock and retards the spark timing to control knock level. Without these devices, manufacturers were forced to set spark timing and compression ratio so that most cars could not knock on regular gasoline inspite of car-to-car variability. The knock-limiter allows manufacturers to raise the compression ratio and control spark so that knock is controlled to trace levels on all cars, regardless of the variations due to manufacturer tolerances on compression ratio and timing. The knock-limiter allows a 1 point increase in compression ratio, equivalent to a 5 percent increase in fuel economy, but is generally not used in high swirl engines where knock is not a serious problems.

Idle speed control which is self explanatory, saves fuel by reducing engine speed during cold start and allowing idle speed to stay constant regardless of accessory loads such as the air conditioner. This device allows the average idle speed to be set at a fairly low level without danger of stall when, for example, the air conditioner is turned on. Note that diesels have a built in speed control system in their fuel injection pump governor. Idle speed control can provide a 2 percent benefit in fuel economy for gasoline engines.

Deceleration fuel shutoff, also self explanatory, saves fuel when using the engine in the braking mode. This has not been possible in carburetted cars because of the time lag between introduction of fuel into the air

stream and its induction into the cylinder. Fuel injection allows the use of such systems, which provide a 2 percent benefit in fuel economy.

Diesel electronic fuel injection, a much more difficult proposition than gasoline fuel injection due to the high pressures involved, can provide small gains in fuel economy. The major impact of these systems is on diesel engine emissions, and will be used with direct injection diesels to allow them to meet emission standards.

Driving aids, although not a form of direct engine control, alert the driver to wasteful driving practices. The principal means have been to signal periods of high fuel use or to signal optimal shift points for manual transmissions. Although gains could depend on driver behavior, the shift point indicator provides a 4 percent fuel economy benefit in the EPA cycle.

Engine shutoff during idle have been made possible when an automatic start/stop system actuated by the throttle is used. This saves fuel during extended idle periods such as city driving and can provide up to 5 percent increase in fuel economy for gasoline engines. (Diesel engines use very little fuel at idle and such a system is not useful in conjunction with diesels).

Electronic transmission control on automatic transmission and CVT's optimize the gear ratio for the particular vehicle speed load condition so that the engine is operating at its best fuel economy. Its use with automatic transmissions has simplified the hydraulic controls and optimized shift points and torque converter lock-up. A fuel economy gain of 3 percent is forecast for such controls, and a similar gain is expected in conjunction with a continuously variable transmission (CVT).

3.6.2 Application

Most of the controls described are either available now in limited model lines or operational in experimental cars. With the exception of diesel fuel injection and transmission control, most of the controls described are applicable only to gasoline engines. Many foreign cars such as BMW and Jaguar offer electronic multipoint fuel injection with deceleration fuel shutoff. Domestic cars, notably from GM, have offered TBI and the knock-limiter in several model lines. Toyota and VW have unveiled the engine stop/start systems and will introduce them in their domestic markets next year. VW and Nissan are offering a drivers aid for optimizing the gear shifts in their Rabbit and Sentra. Electronic diesel fuel injection systems have been unveiled by Lucas, Bosch and United Technologies.

In passenger cars, the application of these technologies appear certain, as vehicles require a microprocessor for emission control to meet the 1988 1.0 g/mi NO_x standard. Addition of other functions to the microprocessor are low cost options compared to the cost of microprocessor. Customer reaction to most technologies should be favorable, because they offer increased performance and reduced maintenance. (Repairing the microprocessor control itself is difficult, but since it is required for emissions, this issue is not addressed in this analysis). The knock-limiter may produce adverse customer reaction because it controls knock to trace levels, thus never getting completely rid of knock. The effect of stop/start systems is difficult to judge because of customer fear of failure to restart the engine. The stop/start system will also affect accessories, and shutoff of the air conditioning system in particular may not be desirable.

3.6.3 Costs

All the estimates of cost assume that emission standards force the introduction of microprocessor controls. Moreover, for multipoint fuel injection,

incremental costs account for savings associated with air pump deletion and deletion of other emission related components. The costs are as follows:

• Idle-speed control	\$20
• Throttle-body fuel injection	\$40
• Multipoint fuel injection	\$65 (4-cylinder) \$80 (6-cylinder) \$90 (8-cylinder)
• Shift indicator lights	\$20
• Transmission control	\$30
• Deceleration fuel shutoff	\$20 (assumes MPFI)
• Knock-limiter	\$40
• Engine stop/start system	\$120

3.7 IMPROVEMENTS TO TRANSMISSIONS

3.7.1 Engineering Description

Current automatic transmissions use a hydraulic system to transmit the engine power to the drivetrain. There is no direct mechanical linkage of the engine to the transmission; instead power is transferred by a torque converter. The flywheel, which is attached directly to the engine's crankshaft, also is bolted directly to a part of the torque converter termed the impeller. The impeller fan sets up a motion of the hydraulic fluid (transmission oil) and this in turn spins a centrifugal fan, which is not mechanically connected to the impeller.

During periods of acceleration, this hydraulic system allows the driven member (centrifugal fan) to turn more slowly than the driving member (impeller). This process is termed torque multiplication. The automatic transmission allows for greater torque multiplication than does a manual transmission with the same number of gears and with the same gear ratio, because in the latter, the speeds of the driven gear are fixed mechanically.

Although this hydraulic system is useful during acceleration, the fuel economy of this sytem is degraded during cruise conditions when the torque converter begins to slip. This slippage causes a loss in fuel economy because, during constant speed conditions, it is more fuel efficient for both members to revolve at the same rate. In order to rectify this situation, automobile manufacturers have been developing a system to mechanically link the driving and driven members during cruise periods. This sytem, termed a **torque converter lockup**, eliminates slipping and consequent fuel economy losses.

The fuel economy of automatic transmissions also can be improved by the use of four forward gears rather than the three currently used in most American automatic transmissions. This is because an extra gear allows a lower numerical gear ratio than in today's automatic transmission. The same principle is involved in overdrive manual transmissions, where a fifth gear is added to the existing four.

Currently, all conventional rearwheel drive automatic transmissions have a torque converter lockup on the third gear of their three-speed transmissions. Ford and General Motors introduced the Integral Overdrive Transmission in 1980/1981 on some of their automatics. This a four-speed transmission with a lockup in the third and fourth gear. GM has introduced an overdrive automatic transmission in 1985 for their front-wheel drive luxury cars. Four-speed transmissions have been available in Mercedes Benz automobiles for many years and are available on all models offered. Toyota recently has added an automatic overdrive transmission. Almost all manufacturers have offered overdrive manual transmissions as of 1982.

3.7.2 Performance

An overdrive transmission (manual or automatic) needs careful matching to engine characteristics and axle ratio to provide optimum fuel economy gains. In general, the use of overdrive results in lower engine speeds

on the highway which, in turn, decreases noise and vibration levels. However, performance in overdrive also suffers and downshifts are required to negotiate gradients or provide highway passing performance. In city driving, overdrive is of little value, since vehicle speeds are never high enough to spend any substantial portion of urban mileage in overdrive.

Torque converter lockup clutches, on the other hand, result in driveline vibrations being transmitted to the body. The locking-unlocking action can also be annoying because of the slight jerk to the vehicle. Thus, their use in small diesels or gasoline engines with fewer than 4-cylinders--engines that have inherently high vibration levels--are likely to cause more customer complaints than in a vehicle equipped with larger, smoother engines. In fact, in recent years TCLU's have been removed in vehicles with 4-cylinder engines.

3.7.3 Cost

Torque converter lockup (TCLU) clutches are not offered as options but as standard equipment. DOT has estimated the price of TCLU units to be about \$35, based on manufacturer data. Overdrive manual transmissions are generally priced as an option over four-speed manual transmissions at \$75. Overdrive automatic transmissions are priced at \$150 over three-speed automatic transmissions.

3.7.4 Fuel Economy

TCLU clutches provide a 3.5 percent increase in fuel economy when the unit locks up only in top gear. Lockup in all gears results in a 5 percent improvement in fuel economy. Overdrive automatic transmissions provide a 15 percent increase in fuel economy, while overdrive manuals provide about a 12 percent increase in fuel economy on the highway and little gain in city driving. Typical fuel economy gains in composite driving are 8 and 5 percent, respectively.

3.8 CONTINUOUSLY VARIABLE TRANSMISSIONS

3.8.1 Engineering Description

Current transmissions feature a discrete number of gear ratios (usually 3 to 5) that determine the ratio of engine to vehicle speed. This results in some loss of flexibility in matching the engine speed/load condition to vehicle requirements. A continuously variable transmission (CVT) offers a continuous choice of ratios between fixed limits, allowing an optimization of engine operating conditions to maximize fuel economy.

Although there are several designs being tested, the CVT that appears to be closest to production features two conical pulleys driven by metal belts. The position of the belts on the conical pulleys determine the gear ratio between input and output shafts. Under steady state conditions, the metal belt system is less efficient than a conventional gear system, but the fuel used over a complete driving cycle is decreased because of the optimized speed/load conditions for the engine.

Current CVT's are designed as replacements for conventional automatic transmissions and are not significantly more efficient than a wide ratio 5-speed manual transmission or an advanced overdrive automatic transmission.

The CVT is expected to find application only in small cars (and possibly in very small trucks like the VW pickup) because: 1) CVT's are inherently torque limited due to the metal belt design and are, thus, not compatible with engines over 2 litres (120 CID) in displacement; and 2) CVT's are attractive for small front-wheel drive cars because they are easier to "package" than a four-speed automatic transmission. The performance, cost and fuel economy gains are discussed below.

Several major suppliers are experimenting with CVT's, but Borg-Warner and Van Dorne (Europe) appear to have the edge on this market in having

an advanced reliable design. Both Ford and GM are known to be testing this CVT for possible introduction in the late 1980's in the subcompact and commuter class of cars.

Performance of the CVT should be equal to or somewhat better than conventional automatic transmissions. However, a CVT can produce unexpected changes in engine speed--i.e., speed dropping while the vehicle speed is increasing--which may deter consumer acceptance. The consumer price of the CVT is expected to be about \$100 over a conventional automatic transmission, while fuel economy is expected to improve by 10 percent over a conventional three-speed automatic transmission. Developments in the metal belt system coupled with downsizing of future cars are expected to enhance the availability of the CVT for use in the compact size classes of cars in the post-1990 time frame.

3.9 WEIGHT REDUCTION

3.9.1 Engineering Description

One of the most important determinants of vehicle fuel economy is vehicle weight. Lower vehicle weight reduces the forces required to accelerate a car, which in turn reduces fuel consumption. There are three principal methods to reduce vehicle weight, namely:

- Conversion to front-wheel drive
- Downsizing
- Material substitution
- Use of unit body construction

Conversion to front-wheel drive reduces weight because: 1) the driveshaft and rear axle are eliminated, and 2) a vehicle of given interior room can have smaller exterior dimensions due to more efficient packaging.

Downsizing reduces vehicle weight by decreasing the size. This process, however, does not conserve interior room for cars, and results in a loss of utility.

Material substitution requires the substitution of high strength steel alloys or plastics for plain carbon steel, which now accounts for over two-thirds of a vehicle's weight. In most cases, this involves redesign of the part to optimize for strength.

Unit body construction refers to the elimination of the conventional chassis/body structure. Prior to 1978 most vehicles utilized a separate chassis that carried all vehicle loads, and the body was suspended on the chassis. Unit body vehicles utilize the body panels as stressed members that carry the vehicle load. Elimination of the chassis results in a 8-10 percent reduction in vehicle empty weight.

Between 1980 and 1983, many domestic cars have incorporated all four methods of weight reduction described below. Almost all cars now feature unit body construction.

Conversion to front-wheel drive began with the introduction of the Omni/ Horizon in 1978 and the GM X-car in 1979. In general, most of these conversions have maintained interior volume in comparison to their rear-wheel drive predecessors, thus permitting comparisons of fuel economy gains and cost changes. Using data from the X-car and the Ford Escort, conversion to front-wheel drive results in a 12 percent fuel economy gain at an approximate incremental price of \$150.

Downsizing occurred primarily during the 1975-1980 era. Even though the exteriors of the cars were much smaller, interior volume declined only slightly. Additional downsizing of cars may occur in the 1985 to 1990 period, but will be limited by its effect on interior volume. This downsizing does not account for "mix shift" which is treated separately. No further downsizing of cars is forecast after 1986/87 because of the loss in interior volume.

3.9.2 Weight Reduction and Cost

Material substitution has not been much in evidence, inspite of extensive promotional efforts. Manufacturers have adopted new materials at a very slow rate to minimize tooling changes and risks associated with new materials. Table 3-3 illustrates the changes in material composition of a compact car between 1980 and 1985. Note that plain carbon steel accounts for nearly 50 percent of the vehicle's weight, even in 1985. This is principally because manufacturers have utilized downsizing and conversion to front-wheel drive as the major sources of weight reduction in the 1980-1985 period.

Material substitution is likely to accelerate in pace after the gains available from other sources have been exhausted. In the post-1985 time frame, the major materials considered for substitution are:

- High strength low alloy steel (HSLA)
- Reinforced Injection Molded (RIM) Plastic Components
- Sheet-Molding Compound (SMC) for body panels
- Aluminum
- Graphite Fiber Reinforced Plastics (GRP)
- Advanced Composites

Other materials such as zinc and magnesium also will be used, but in lesser quantities. Costs associated with these materials vary by the particular requirement for the component, e.g., stiffness, bending strength, formability. In general, HSLA is the lowest cost increment and is compatible with tooling equipment used for plain carbon steel. Plastics (RIM and SMC) also are fairly low in cost but require new manufacturing and finishing techniques. Aluminum represents a fairly high cost option but also is capable of producing large reductions in weight. GRP and advanced composites represent the highest cost option and produce the greatest weight savings.

TABLE 3-3
MATERIAL COMPOSITION FOR TYPICAL DOMESTIC
COMPACT PASSENGER VEHICLE

<u>Material</u>	<u>1980</u>	<u>1985</u>
High Strength Steel	(5%)	(11%)
Aluminum	(4%)	(7%)
Plastic	(6%)	(9%)
Glass	(3%)	(3%)
Rubber	(4%)	(3%)
Iron	(14%)	(11%)
Plain Carbon Coated Steel	(52%)	(47%)
Fluids, Lubricants	(5%)	(5%)
Others	<u>(7%)</u>	<u>(4%)</u>
CURB WEIGHT (LBS)	3200	2600

The Department of Transportation (DOT) has performed detailed studies of weight reductions possible in each size class of car for four cases--HSLA dominant, Reinforced Plastics dominant, Aluminum dominant, and GRP dominant. The resulting weight reductions are detailed in Table 3-4. Although no one case will be representative of any manufacturer's strategy, EEA believes that the lowest cost materials will be used first in the 1985-1990 time frame. This indicates that the most likely weight range will lie near those predicted for the HSLA and Reinforced Plastics cases. In the post-1990 period, Aluminum and GRP may be used if the costs can be justified in fuel savings. DOT has predicted an average cost of \$0.50 per pound saved for high HSLA designs and plastics, \$0.75/lb saved for Aluminum and \$1.00/lb saved for GRP and advanced composites.

3.8.3 Fuel Economy Benefit

The actual fuel economy benefit obtained depends on the extent of weight reduction. It is important to note that weight reduction efforts that do not decrease weight by at least 5 percent of initial weight will not improve EPA fuel economy due to the test procedure employed that requires discrete weight changes of 125 or 250 lbs. Manufacturers design to these specifications and the planned weight reduction is usually close to either 125 or 250 lbs (or multiples) when a new model is introduced. Based on detailed analysis of the fuel economy data base, EEA has found that:

- Weight reduction of 10 percent accompanied by engine size or axle ratio reduction for constant performance results in a 6.6 percent gain in fuel economy.
- Weight reduction of 10 percent unaccompanied by any change to the engine or drivetrain results in a 2.2 percent gain in fuel economy.

3.10 IMPROVEMENTS IN AERODYNAMICS

3.10.1 Engineering Description

Aerodynamic drag is a resistance force on a moving car's surface area caused by wind intensity and direction. Aerodynamic drag is a function

TABLE 3-4
WEIGHT REDUCTION THROUGH MATERIAL SUBSTITUTION

	<u>Base*</u>	<u>HSLA</u>	<u>Plastics</u>	<u>Aluminum</u>	<u>GRP</u>
Small Car	2150	1821	1794	1561	1467
Compact Car	2600	2310	2265	2040	1870
Large Car	3586	3022	2979	2781	2429

*1985 baseline

Small car: Ford Escort

Compact car: Chevrolet Citation

Large car: Chevrolet Impala/Caprice

of a car's frontal area and body shape. The drag coefficient is a measure of the streamlining of the car body. The higher the coefficient, the greater the drag; the larger a car's frontal area, the higher the drag. Drag-related power requirements are a cubic function of a car's speed through the air. Drag has a minimal effect at low speeds and a strong impact at high speeds, so that reduction in drag affects highway fuel economy much more than city fuel economy.

Aerodynamic drag cannot be reduced without affecting many other characteristics of the automobile. Since drag depends on body shape and frontal area, a change in drag characteristics can impact the vehicle's interior volume and its utility to the consumer. For example the drag force could be drastically reduced by narrowing the car width to accommodate two people per seat instead of three. However, this would drastically affect the car's carrying capacity. Streamlining of the vehicle's shape is subject to these limitations as well as public acceptance of highly aerodynamic shapes.

Since aerodynamic drag is so inextricably related to vehicle design, it is not feasible to distinguish the application of improved aerodynamics from styling designs in current vehicles. There is no question that greater attention is being paid to the vehicle's drag coefficient, but this has always been compromised by styling requirements as discussed below.

3.10.2 Performance

Recently introduced cars such as the J-body and the Tempo have drag coefficients in the 0.4 range. Research studies have shown that cars with highly aerodynamic shapes that can still seat four and provide adequate vision, have drag coefficients as low as 0.23 0.25.

Practical limitations result in different aerodynamic improvements to different size classes. Minicompacts, for example, are limited by packaging constraints and will show the least improvement in drag coefficient, while large cars can show the greatest improvements. Aerodynamic improvements do not affect performance in any way, but styling can be strongly influenced, especially in the post-1985 time frame.

3.10.3 Fuel Economy and Cost

A 10 percent reduction in drag translates to a 3.3 percent increase in composite fuel economy. Thus, a maximum feasible fuel economy gain of about 25 percent is available. In the 1980-1985 term, most of the vehicles were redesigned so that the drag coefficient is comparable to the X and J-body cars, i.e., about 0.40, resulting in a 6 percent increase in fuel economy. In the 1985-1990 period, industry observers predict that average drag coefficients will decline to about 0.35, resulting in a 4.8 percent increase in fuel economy. By the year 2000, widespread public acceptance of highly aerodynamic designs could result in average drag coefficients as low as 0.28, resulting in another 5 percent increase in fuel economy. Ford has taken the lead in aerodynamics and will introduce the Taurus in 1986 with a C_D of 0.31.

The costs of aerodynamic improvements are embodied in the expenses of research to lower the drag coefficient and are essentially inseparable from styling costs. Based on manufacturer submissions, DOT has estimated that the cost of an air dam under the front of the car and a rear spoiler amount to about \$15.00. We have estimated that each 0.05 C_D reduction will cost double the previous 0.05 reduction with the initial cost of going from a C_D of 0.45 to a C_D of 0.4 placed at \$20.

3.11 TIRES, LUBRICANTS AND ACCESSORIES

Small gains in fuel economy can be attributed to:

- Decreasing rolling resistance due to tire improvements
- Decreased viscous and frictional losses from advanced synthetic lubricants
- Reduced accessory power loss.

3.11.1 Tires

The use of radials over bias-ply tires has been widespread and now account for 100 percent of the new car fleet. Recent improvements such as high pressure P-metric radial tires offer an additional 2 percent gain in fuel economy over "conventional" radial tires. Thus, a 2 percent gain in fuel economy is available for the 1980-1985 time period. However, the new high pressure tires provide a rougher ride and increased road noise, and may cause some customer objection. In fact, Chrysler decided not to use such tires in the 1982 LeBaron, which is a premium version of the K-car. In the 1985-1990 time frame, low-profile radials with improved rubber and tire cord formations will result in another 2 percent improvement in fuel economy. New tire construction methods currently in the research phase show that plastic compounds can be cast into tire shapes, eliminating cord pumping and hysteresis losses. Such tires are expected to provide a 7 percent improvement in fuel economy over current tires (i.e., 3 percent over the post-1985 tires) and are expected to be introduced in the early 1990's. The initial cost of the radials is placed at \$20, of low-profile radials at \$40 and the injection molded tires at \$50. All prices are for four tires and are incremental prices over bias-ply tires.

3.11.2 Lubricants

Lubricants are expected to provide gains in fuel economy through improved formulations that reduce the viscosity index (VI) and through the addition of friction modifiers. In the 1980 to 1985 term, a 2 percent improvement

in fuel economy (already available in several models) will come from the use of improved multigrade oils. In the 1985-1990 time period, EEA expects an additional 1 percent improvement from synthetic oils and VI improvers. Friction modifiers, which have been found to increase engine wear, and synthetic lubricants may be available for use in the 1990's with suitable wear protection additives for another 2 percent gain in fuel economy. All of the above fuel economy gains include the effects of engine, transmission, and rear axle lubricant modifications. Cost of improved multigrade oils are placed at \$2.50 (for 5 quarts), while for synthetic oils it is \$7.50 over conventional oils.

3.11.3 Accessories

Accessory drives absorb power from the engine and their influence is inversely related to engine size. In cars, the cooling fan, water pump, alternator, power steering pump, and air conditioner (when used) can account for a major (15 percent) penalty in fuel consumption. Efficiency improvements in all of these accessories and conversion to thermostatically operated electronic cooling fans can provide up to a 3 percent improvements in fuel economy. All of these improvements are being phased in during the 1980-1985 time period.

An additional 2 percent improvement in fuel economy is possible through redesign of the drives and improvements in fan blades coupled with reduced heat rejection from the engine. These improvements will be phased in during the 1980-1985 period. Costs for such improvements (except the electric fan) are small, typically amounting to about \$10.00 per vehicle in each time frame.

In the 1990-1995 period, electric power steering may be used instead of the conventional system using a hydraulic pump. EEA estimates that this system will provide a 2 percent gain in fuel economy for an incremental price of \$25.

3.12 ALTERNATIVE POWER PLANTS

Although current tooling plans and industry research indicates that conventional (piston) spark ignition and diesel engines will continue to be the dominant power plant to 2000, there are a number of alternative candidates for possible introduction in the 1990's. They are briefly described below.

3.12.1 Wankel

The Wankel engine has been available for nearly a decade in limited production. There are some suggestions that a stratified charge Wankel engine could become a contender in the next decade. This Wankel concept is being actively researched by Mazda and Toyota, while GM has a low level program in this area. Although the Wankel provides a high power to weight ratio and is vibration free, it has two inherent weaknesses:

- A high surface area to volume ratio that results in high heat transfer
- High sliding friction from the rotors

Such problems could be solved in the future, but EEA's review of published data shows that improvements are likely to increase fuel economy only to a level that is competitive with current conventional gasoline engines. EEA projects that the Wankel engine is more likely to be introduced for its smoothness and power, rather than for fuel economy reasons.

3.12.2 Stirling

The Stirling engine is theoretically capable of reaching ideal (Carnot cycle) efficiency. The concept, first invented in the 1800's has been difficult to implement. Current versions of a Stirling engine are difficult to describe because of their complexity. In brief, the Stirling uses an enclosed working gas (usually hydrogen) which is heated in the heater head, and expanded through a piston expander. Waste heat in the

expanded gas is transferred back to the compressed gas in a continuous cycle. Since the working gas is enclosed and heated separately, the Stirling engine can use a continuous combustion burner. This enables it to use virtually any fuel and provide very low emissions. Its ability to convert most of the available heat to work results in its high theoretical efficiency.

In practice, the Stirling's theoretical gains have proved difficult to achieve. The engine is being developed by United Stirling of Sweden and Mechanical Technology, Inc. (under contract to DOE). Hydrogen containment has been a major problem. Its efficiency depends on maximizing the heater head temperature, which in turn requires the use of expensive alloys or ceramics. Throttling of the Stirling engine also has been difficult to achieve without large efficiency losses.

The program goal for the Stirling engine is to be 30 percent more efficient than a conventional gasoline engine. DOE and its contractors estimate that the cost increase of a Stirling over a conventional s.i. engine is likely to be around \$1,500. Given that the direct injection diesel is likely to be 50 percent more efficient than a gasoline engine, the prospects for the Stirling engine as an alternative powerplant for cars or trucks are very poor. In fact, United Stirling performed a market survey which concluded that the most likely application was for auxiliary power sources or industrial vehicles (fork lift, trucks, etc.) where low emissions are a principal requirement.

3.12.3 Gas Turbine Engines

Sometimes referred to as the Brayton cycle engine, the gas turbine provides a vibration-free powerplant that can burn any ashless liquid fuel. The engine consists of a rotary compressor, which boosts the pressure of incoming air, a combustor where the high pressure air is mixed with fuel and heated to combustion, and a turbine where the hot

compressed gas are expanded to provide power. A single shaft gas turbine has the turbine and compressor connected to the output shaft; a two-shaft gas turbine utilizes two separate turbine stages to run the compressor and to provide output power. This allows output shaft speeds to be virtually independent of compressor speed, providing greater flexibility for varying speed and load. In addition, automotive gas turbines utilize a regenerator to capture exhaust heat and transfer it to the intake air.

The gas turbine's efficiency depends directly on combustion temperature and the turbine therefore requires high temperature alloy steels or ceramics. At these high temperatures, a gas turbine has been proven to be as efficient as a current diesel engine. In addition, the gas turbine has no requirement for fuel of a specific octane or cetane number and can burn any fuel with low emissions in comparison to a diesel engine. The turbine engine does suffer from several inherent problems, namely:

- The turbine is as efficient as the diesel only near full load operating conditions. Part-load and idle fuel economy are substantially inferior to a diesel engine.
- The high inertia of the turbine gives rise to poor throttle response in stop and go conditions compared to a conventional gasoline engine. Throttle response, however, is comparable to a turbocharged heavy truck diesel engine.
- The turbine engine is not scaled down easily. Viscous losses and turbine tip leakage losses become increasingly more significant as the engine is made smaller.

On the positive side, a two-shaft turbine engine needs a simpler transmission, and maintenance periods and useful life are much longer than for piston engines.

The turbine is likely to find acceptance only in large or luxury cars where engine horsepower requirements are high and there is considerable emphasis on smoothness and quietness. All of the world's major manufacturers have experimental prototypes under construction or in operation. In the U.S., the DOE is funding Ford, GM, and Chrysler in a competitive

build with project completion planned for 1985. The vehicles in which the gas turbines are to be installed are the size of today's compacts which will be comparable in weight to future full size cars. In Europe, Mercedes, VW and Volvo have experimental versions currently in operation. They claim that fuel economy is comparable to that of a conventional gasoline engine. Turbine engines are likely to have a cost penalty estimated at \$1,200 over a gasoline engine. This implies that consumers are likely to buy turbine engines in large numbers only if a cheaper low grade fuel becomes available for use in turbines, or if the low noise and vibration characteristics are of special value to a group of consumers.



4. FORECASTS OF FUEL ECONOMY BY SIZE CLASS

4.1 OVERVIEW

The Technology/Cost Segment Model (TCSM), described in Section 2 of this report, was utilized to forecast fuel economy by size class and manufacturer for the various fuel price scenarios considered. In effect, the technological improvements described in the previous section are utilized to improve fuel consumption of automobiles in the future. The TCSM utilizes 1978 as the "base" year from which technological improvements and their costs are calculated by model line. The major steps in performing the forecast are:

- Organizing each manufacturers' different models to common "platforms" and assigning the platforms to five "size" classes--minicompact, subcompact, compact, intermediate, large/luxury. Although EEA refers to them as size classes, they are more accurately termed market classes and the classes are consistent with the 1984 industry market classes, rather than the U.S. EPA defined size classes. The two classifications are approximately equivalent, but the classification of some individual models are different.
- Allocating the different technological improvements available to the individual platform lines based on the design life cycle of each platform. The model year in which a technology can first be adopted to a specific platform is developed from the study of each manufacturer's product plan. This plan controls the release of new technology and the pace of fuel economy improvement in the future.
- Controlling the decision to adopt or reject on available technological improvements based on U.S. fuel prices. As explained earlier, manufacturers are expected to sell models in Canada whose technologies are determined by U.S. conditions, primarily fuel prices. Thus, the technology level of each platform varies primarily with U.S. fuel prices, but Canadian fuel prices are used to determine the level of "discretionary" technology penetration, namely diesels, turbochargers and mix of engines. Engine electronic controls that affect emissions (such as fuel injection) are an exception as they are influenced by the Canadian emission regulations.

Each of the specified six scenarios represent combinations of four specified Canadian fuel price paths and three U.S. fuel price paths. In each scenario, the different levels of non-discretionary technology and discretionary technology adoption gives rise to different levels of fuel economy by platform, and "size" class. The combination of the size class specific fuel consumption values to the Corporate Average Fuel Consumption is accomplished with a forecast of the size class mix by manufacturer, that is detailed in Section 5 of this report.

The major influence of the product plan of each manufacturer on the level of fuel economy attained must be noted, as the assumption in this report is that the specified base case for fuel prices is equivalent to current manufacturer expectations of fuel price; that is, manufacturer's current product plans (as of December 1984) reflect the manufacturers behavior under the base case. The importance of the base case lies in the fact that all other scenarios were developed as perturbations of base case (current) manufacturer product plans to suit the alternative fuel price scenarios employed.

Most of the forecasts are summarized in the tables accompanying this section, and the major features of the forecasts under each scenario are briefly described below.

4.2 BASE CASE

Under this case, fuel prices in Canada remain approximately constant in real terms during the period 1985-1995, while fuel prices in the U.S. stay constant between 1985-1988 and climb at a 4.3 percent annual rate in real terms during 1989-1995. The 1995 U.S. real price is approximately equivalent to the 1980 real price.

The product plans of the four domestic manufacturers--AMC, Chrysler, Ford and GM are detailed in Tables 4-1 through 4-4, by size class. The

product plans through 1989/90 are based on actual plans as of December 1984, and the plans in the '90-'95 time frame are based on the assumption of a 7 or 8 year model life cycle, with a reskin midway through the model's life. The major features of the base case are:

- retains rear-wheel drive (RWD) for all its or sporty cars except the
- retains only for the and
- converts its lines to
- Diesel market share is about 1 percent in 1995
- Advanced material substitution (aluminum, FRP and GRP) is not implemented
- The penetration of 4-valve high performance engines is about 20 percent, essentially replacing all V-8's by 1995
- Aerodynamic styling is restricted to a $C_D = 0.34$ on average by 1995

The detailed Tables 4-5 through 4-26 show the fuel economy of each platform and size class for the four manufacturers. An even more detailed set of tables showing the adoption and market penetration of each technology by platform is presented in Appendix A.

Table 4-27 summarizes the base case forecast of fuel consumption by size class for each manufacturer.

4.3 ALTERNATE SCENARIOS

4.3.1 Case 2 - Smooth Rise

Under this scenario, the U.S. fuel price stays at the same level as in the base case, but Canadian prices rise at 4.75 percent so that 1995 prices are 52 percent higher than 1986 prices in real terms. Since the U.S. prices are identical to those used in the base case, the pace of major technology adoption is identical to that in the base case. However, discretionary technology adoption patterns sensitive to Canadian fuel

price paths are different, and consumers choose more efficient transmissions (overdrive) and smaller engines so that individual platform fuel economy is 5 percent higher than the base case in 1995. In addition, diesel penetration rises to 5 percent of the domestic fleet for an incremental fuel economy gain of 1.2 percent in 1995. The results of this Scenario are summarized in Table 4-28.

4.3.2 Case 3 - Shock in 1987

Under this case, fuel prices rise by 50 percent in 1987 over the base case due to a "supply shock", and the price rise occurs in both the U.S. and Canada. In the post-1987 time frame, prices rise at the same rate as in the base case so that the 1995 price is still 50 percent above that forecast in the base case for both the U.S. and Canada.

Because of the large shock in prices, a large change in product plans is assumed. Changes are, however, implemented beginning in 1990 (given the manufacturers lead time requirements) and the major changes are:

- All vehicles except the and are converted to FWD
- The direct-injection diesel with turbocharging is introduced and diesel penetration of the domestic fleet is 10 percent in 1995
- All V-8 and V-6's are converted to 4-cylinder/4-valve engines, with a resulting penetration of about 40 percent
- All through material substitutin with aluminum and advanced composites is not quite cost-effective at even these high fuel prices, manufacturers fear of further supply shocks result in adoption of these materials
- Very highly aerodynamic styling is adopted so that average C_D declines to 0.28

The results of this scenario are shown in Table 4-29

4.3.3 Case 4 - Low Fuel Price

Under this scenario, fuel prices in both the U.S. and Canada decline linearly so that by 1995, the price in either country is 50 percent below those assumed in the base case. As a result:

- and () to 1995 and
- "Saturn" type projects for the subcompact segment are cancelled
- Mini-cars are phased out due to lack of consumer interest
- No material substitution is implemented after 1988 (i.e., after currently planned improvements are implemented)
- The market moves to high performance engines
- Plans for advanced transmissions do not go beyond what will be available in large cars in 1988

Results of this scenario are shown in Table 4-20.

Two other scenarios differ from the four described only in the mix of sizes employed and are detailed in Sections 5 and 6 of this report, accordingly.

TABLE 4-1

5. FORECASTS OF AUTOMOBILE MARKET SHARES BY SIZE CLASS AND MANUFACTURER IN CANADA

5.1 INTRODUCTION

The development of forecasts of Corporate Average Fuel Consumption requires estimates of new car market shares by vehicle size class (as used in the TCSM) and by manufacturer. This section discusses the data and methods used to develop these estimates. Section 5.2 briefly reviews historical (1976- 1984) trends in the market. The development of a methodology to forecast market shares by size class is outlined in Section 5.3. Projections of size class/manufacturer market shares through 1995 are provided for the Base Case and each alternative fuel price scenario in Section 5.4 and 5.5.

5.2 HISTORICAL TRENDS

Table 5-1 present the historical distribution of market share by size class.* Over the 1976 to 1982 time period significant shifts occurred in the market shares of subcompacts and large cars as consumers responded to sharply rising fuel prices and manufacturers commenced vehicle downsizing programs. The subcompact car share more than doubled from 20 percent in 1976 to 46.4 percent in 1982, while the large (standard) car share dropped by more than half from 25.8 percent to 12.2 percent of the market over the same time period. The share of intermediate and compact cars also declined over the 1976-1982 time period, although the drops

*Although the term size class is employed, EEA works with "market class" based on the industry classification of vehicles by market intent. As a result, some of the distributions shown here may differ from those calculated using a strict size class based definition.

TABLE 5-1

were not nearly as significant as those of the large car class. The relatively small losses in market share of these two classes reflected the shifts caused by manufacturer downsizing of large cars to the intermediate category, downsizing of intermediates to compacts (i.e., introduction of the GM X-body and Chrysler K-car compacts in 1980 and 1981, respectively).

With stable or declining fuel prices during the past 2 years, the 1983-84 trend in market shares by size class has reversed the patterns observed from 1976 to 1982. Both intermediate and large cars gained slightly in market share between 1982 and 1984 while the shares of subcompact and compact cars declined. In 1984 subcompact cars accounted for 43.7 percent of the market, compacts had a 21.0 percent share, intermediate held a 21.9 percent share, and large cars had 13.3 percent.

Table 5-1 also summarizes the trend in new car market shares by origin of manufacturer. As in the U.S., Canadian domestic manufacturers lost market share to the imports during the 1976 to 1984 time period. Between 1976 and 1982, domestic market share fell from 85.7 percent to 70.2 percent. Propelled by the Japanese, the import share rose from 14.3 percent to 29.8 percent of the market during the same time period. Over the following 2 years (1983-1984), however, the import share fell to 23.9 percent--largely as a result of declining Japanese penetration due to the imposition of Canadian-Japanese Voluntary Restraint Agreements in 1982. As shown in Table 5-1 the imports have been a major player in the small car end of the market, accounting for 56 percent of the total subcompact share in 1984. Imports also have significantly increased their share of the large car segment from about 7 percent in 1976 to 31 percent in 1984.

Within the domestic market, General Motors has been the dominant factor. GM's market share rose from 46.5 percent in 1976 to 59.3 percent in 1980 largely at the expense of Chrysler (see Table 5-1). Although Chrysler

recaptured market share in the 1980's, GM still retained the largest slice of new car sales. In 1984, GM accounted for about 50 percent of the market, and Chrysler and Ford held 23 percent and 22 percent shares, respectively. American Motors/Renault accounted for the remaining 5 percent.

5.3 DEVELOPMENT OF A MODEL TO FORECAST SIZE CLASS MIX IN CANADA

As indicated earlier, the development of Corporate Average Fuel Consumption projections using the TCSM required forecasts of new car sales by size class. An initial survey of the literature showed that although a number of models were available to forecast new car sales by size class in the U.S., there was little or no information on similar models to project the size class mix of new cars in Canada. Therefore, we reviewed the literature on models of size class mix in the U.S. in an effort to specify a similar model for Canada. Our review showed that the following variables were generally significant determinants of new car market shares by size class:

- Average new car price by size class
- Average price--all new cars
- Distribution of households by income bracket
- Distribution of households by size
- Number of licensed drivers per household
- Population distribution by age
- Personal disposable income per capita (or household)
- Unemployment rate
- Average price of gasoline
- Annual change in gasoline price
- Consumer price index

Data from 1976 through 1984 were collected from Canada on seven of the eleven variables listed above*. Using these data we developed several alternative specifications of new car market shares (expressed in percent) as functions of real fuel prices, real disposable income per capita, the annual change in real fuel prices, number of licensed drivers per household, and the unemployment rate. In all of these initial regression analyses, the licensed drivers per household variable and the unemployment rate variable were highly insignificant and were dropped from further use.

Following the available literature on models of size class market shares in the U.S., several functional forms of a Canadian size class model were developed and tested. These included regression models of a: 1) linear, 2) log-linear, and 3) non-linear form. Our initial efforts focused on linear representations of size class market share (expressed in percent) as functions of real fuel prices, the year-to-year change in real fuel prices, and disposable income per capita. As shown in Table 5-2, the linear model provided a relatively good fit of the historical data. Table 5-2 shows linear models of size class market shares (estimated using the SAS GLM statistical package) with and without a disposable income per capita variable. Generally, the income per capita variable, in addition to fuel price, significantly improved the model. Combining the subcompact and compact equations and the intermediate and large equations of Model 1 (in Table 5-2) produced the following net results:

$$\begin{aligned}\text{subcompact} + \text{compact} &= -50 + 1.0 * \text{Price} + 0.8 * \text{YDK}/100 \\ \text{intermediate} + \text{large} &= 150 - 1.0 * \text{Price} - 0.8 * \text{YDK}/100\end{aligned}$$

*Adequate time series data were not readily available for new car prices by size class, household distributions by age or by income, and population age distributions.

TABLE 5-2
LINEAR REGRESSION MODELS OF SIZE CLASS
MARKET SHARES IN CANADA

Variable Name ^a	Subcompact		Compact		Intermediate		Large	
	Model #1	Model #2	Model #1	Model #2	Model #1	Model #2	Model #1	Model #2
Intercept	-104.36 (-5.10)**	-25.26 (-3.51)	54.99 (3.32)	39.39 (12.58)	68.85 (6.14)	32.19 (9.20)	80.54 (4.60)	53.67 (14.44)
Price	1.432 (9.26)	1.802 (7.94)	-0.4343 (-3.47)	-0.5065 (-5.14)	-0.072 (-1.85)	-0.2638 (-2.21)	-0.926 (-6.99)	-1.501 (-8.98)
Delprice	-0.493 (-1.57)	0.0857 (0.15)	0.511 (1.89)	0.3974 (-1.64)	-0.319 (-1.74)	-0.5871 (2.17)	0.300 (1.45)	0.1037 (0.36)
YDK/100	1.002 (3.94)		-0.196 (-0.96)		-0.4646 (-3.33)		-0.3405 (-1.56)	
R ²	0.982	0.925	0.844	0.815	0.913	0.719	0.958	0.938

^aNote: Price = real (\$1981) price of leaded gasoline
Delprice = price of leaded gasoline in current year minus price in the preceding year
YDK = real (\$1981) disposable income per capita

**Numbers in parentheses are t - statistics

Both the price and income coefficients show expected signs, i.e., an increase in disposable income per capita will increase small car market share, and rising fuel prices will reduce the market share of larger cars. The linear models shows that a 1¢ change in fuel price will cause a 1 percent shift in size class market shares. Conversely, a \$125 change in disposable income per capita will produce a 1 percent shift in size class mix.

The size class regression models in Table 5-2 also were estimated in log form. While both the linear and the log models provided a relatively good fit of the historical data, both were asymptotically incorrect and did not work well with the fuel price and income/capita forecasts provided by EMR. In particular, large continued increases in income/capita (as embodied in the EMR forecasts) drove the large car market share to negative values.

To avoid these problems, we explored a non-linear regression model of size class shares as a function of real fuel prices and disposable income per capita. The general form was as follows:

$$\text{MktPct} = 100 * e^{(-C1-P*Price)} + e^{(-C2-I*YDK)}$$

Table 5-3 shows the results (which were estimated using the SAS NLIN statistical regression package). Use of the non-linear form provided a generally good fit to the data for all of the size classes except subcompacts. In particular, the subcompact (small) car equation significantly underpredicted the actual growth in subcompact market shares which occurred during the early 1980's. Attempts to correct for the underprediction by renormalizing the results of all the share equations to equal 100 percent further skewed the estimates. Therefore, for the purpose of forecasting, we assumed that the subcompact share was equivalent to 100 minus the sum of the compact, intermediate and large car shares.

TABLE 5-3
NON-LINEAR REGRESSION MODELS OF
SIZE CLASS MARKET SHARES IN CANADA*

<u>Variable Name</u>	<u>Subcompact</u>	<u>Compact</u>	<u>Intermediate</u>	<u>Large</u>
Price Intercept (c1)	0.000 (0.442)**	0.8654 (0.931)	0.000 (12.573)	0.000 (1.469)
Price	0.0315 (0.243)	0.0193 (0.0369)	0.1334 (0.522)	0.055 (0.104)
YDK	0.00013 (0.00119)	0.00053 (0.0271)	0.00017 (0.00007)	0.00042 (0.0055)
YDK-Intercept (c2)	0.0000 (2.4146)	0.0000 (190.887)	0.0000 (0.675)	0.0000 (36.25)

*Note: The general functional form of the non-linear model is as follows:

$$\text{Pct} = 100 \cdot e^{(-c1 - P \cdot \text{Price})} + e^{(-c2 - I \cdot \text{YDK})}$$

**Numbers in parentheses are asymptotic standard errors

5.4 BASE CASE FORECAST OF MARKET SHARES BY SIZE CLASS AND MANUFACTURER

The non-linear model discussed in Section 5.3 was used together with projections of Canadian fuel prices and disposable income per capita supplied by EMR (see Table 5-4), to develop a Base Case forecast of new car sales by size class. The Base Case scenario essentially assumed the following:

- Nominal Canadian pump price of gasoline will remain constant through 1986, and increase 4 percent/year through 1990 and 5 percent/year thereafter
- In real terms Canadian pump prices will stay relatively constant
- Present level of U.S. CAFE will be maintained to 1995
- U.S. fuel pump price trajectory assumed to be the average of the "low" projections contained in the U.S. Department of Energy, Energy Information Administration, Annual Energy Outlook 1983
- Canada will adopt U.S. emission standards in 1988

The initial Base Case size class projections excluded mini-compacts which, historically, have accounted for a negligible share of the market. In fact, the available historical data were not sufficient to develop a realistic projection of mini-car market share that was sensitive to fuel prices and income. However, since the Japanese and domestic manufacturers are planning to expand mini-compact production beginning in the 1987/1988 time period, we assumed (based on discussions with manufacturers) that the mini-compact share of the total market would rise from 1.3 percent in 1986 to 4 percent in 1990 and 5.9 percent by 1995 in the Base Case. This assumption was then used to re-normalize the Base Case market shares for the subcompact, compact, intermediate and large size categories (see Table 5-5). The forecast generally shows only small movement in the size class mix as shown in Figure 5-1.

The Base Case projection of market shares by size class was further disaggregated by manufacturer using a series of assumptions concerning future trends in import car penetration and the relative competitiveness

TABLE 5-4
 BASE CASE PROJECTIONS OF CANADIAN FUEL PRICES
 AND DISPOSABLE INCOME PER CAPITA
 (1981 \$)

<u>Year</u>	<u>Fuel Price (\$/liter)</u>	<u>Income Per Capita</u>
1981	35.3	9645
1982	38.7	9473
1983	39.2	9365
1984	39.2	9355
1985	37.5	9636
1986	36.1	9383
1987	36.0	10124
1988	36.0	10367
1989	36.0	10615
1990	36.1	10870
1991	36.4	11120
1992	36.8	11376
1993	37.1	11638
1994	37.5	11905
1995	37.9	12179

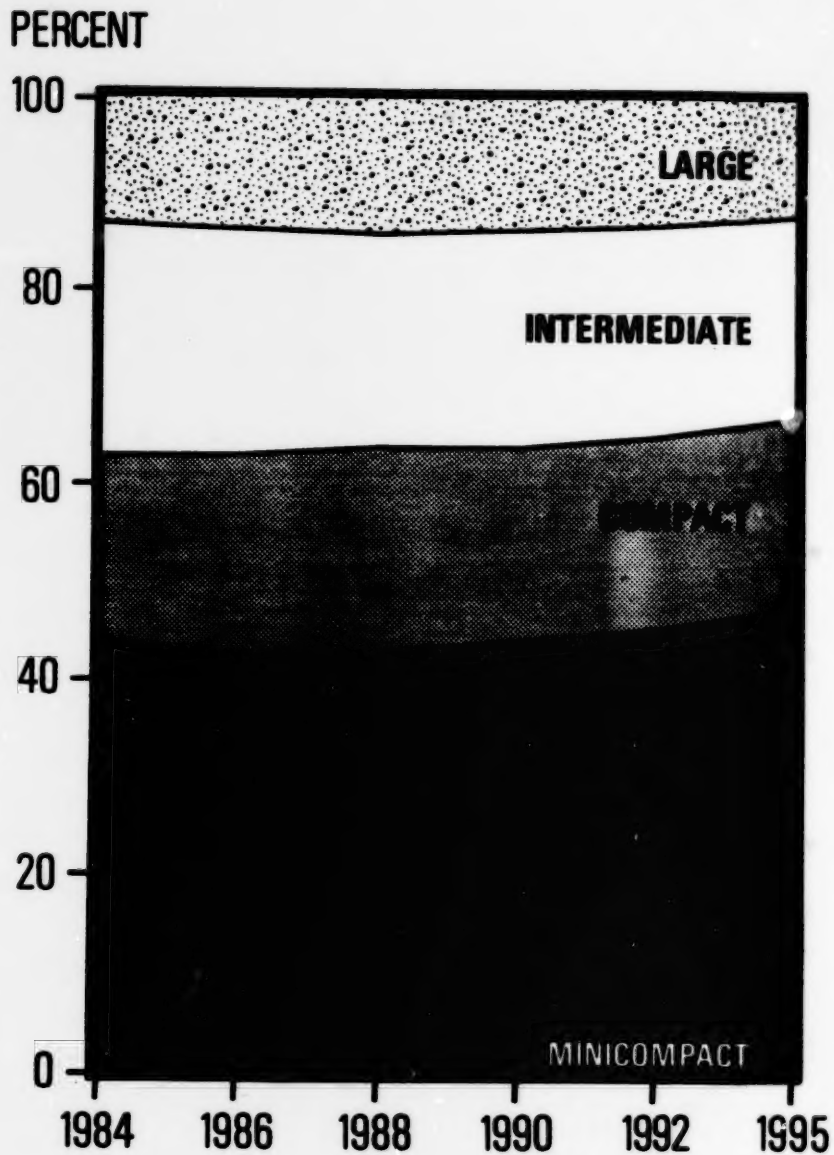
Source: Canadian Department of Energy, Mines and Resources

TABLE 5-5
MARKET SHARES BY SIZE CLASS IN CANADA
BASE CASE
(Percent)

<u>Year</u>	<u>Minicompact</u>	<u>Subcompact</u>	<u>Compact</u>	<u>Intermediate</u>	<u>Large</u>
1986	1.3	41.7	19.8	23.1	14.2
1988	3.2	39.8	20.2	22.6	14.2
1990	4.0	39.7	19.6	22.7	14.0
1992	5.1	40.2	19.3	21.9	13.5
1995	5.9	41.8	18.7	20.9	12.7

FIGURE 5-1

Market Shares By Size Class In Canada BASE CASE



of the domestic manufacturers within each market segment. These assumptions were as follows:

- The import car market share (excluding captive imports) will remain constant at 24.4 percent in 1985-86 and then rise only slightly to 24.6 percent in the 1988-1990 time period as a result of continued restraint by the Japanese on car exports to Canada. By 1995, imports will account for 25.2 percent of the market. The Japanese share of the import market will rise slowly from 66 percent in 1986 to 69 percent by 1995 (see Table 5-6).

TABLE 5-6
MARKET SHARES BY ORIGIN
OF MANUFACTURER
BASE CASE
(Percent)

<u>Year</u>	<u>Domestic</u>	<u>Japan</u>	<u>Europe/Other</u>
1985	75.6	16.1	8.3
1986	75.6	16.1	8.3
1988	75.4	16.7	7.9
1990	75.4	16.8	7.8
1992	75.1	17.1	7.8
1995	74.8	17.4	7.8

Using the assumptions outlined above, a Base Case forecast of market shares by size class and manufacturer was derived. The results are shown in Table 5-7 without further discussion.

5.5 FORECASTS OF MARKET SHARES BY SIZE CLASS AND MANUFACTURER FOR ALTERNATIVE FUEL PRICE SCENARIOS

In addition to a Base Case fuel price projection, alternative fuel price scenarios were provided by EMR as discussed in detail in the introduction to this report. Using the model outlined earlier in Section 5-3, the fuel price trajectories shown in Table 5-8, and the Base Case forecast of disposable income per capita, estimates of market shares by size class were generated for each of the scenarios. These are summarized in Table 5-9. The size class market share projections were then disaggregated by manufacturer based on the assumption that manufacturer shares by size class are similar to the Base Case values across all fuel price scenarios. It should be noted, however, that the minicar market share projections were further adjusted to reflect a steep price decline in Scenario 3 and the anticipated effects of a price shock in Scenario 4. In particular, mini-compact market share in Scenario 4 was assumed to rise rapidly to 6 percent in 1990 as a result of a 1988 price shock and then grow slowly to 7.6 percent by 1995--a reflection of the historical pattern of "surges" of consumer interest in small cars following steep fuel price escalations. Mini compact market share in Scenario 3 was assumed to peak in 1988 and then decline to zero by 1992 as manufacturers leave this market segment response to sharply declining fuel prices.

Table 5-10 through 5-12 present the estimates of market shares by size class and manufacturer. Under a low fuel price case (Scenario 3), GM, Ford and Chrysler gain overall market share at the expense of AMC and the imports relative to the Base Case because of their dominance in the intermediate and large car categories. In contrast, in the price shock case (Scenario 4) and the steady fuel price case (Scenario 2), AMC and the imports gain at the expense of GM, Ford and Chrysler because of their dominance in the minicompact and subcompact market segments.

TABLE 5-7

TABLE 5-7 (cont'd)

TABLE 5-8
ALTERNATIVE PROJECTIONS OF CANADIAN FUEL PRICES
(1981 CENTS/LITER)

<u>YEAR</u>	<u>BASE</u>	<u>SCENARIO 2^{1/}</u>	<u>SCENARIO 3^{2/}</u>	<u>SCENARIO 4^{3/}</u>
1977	28.3	28.3	28.3	28.3
1978	27.1	27.1	27.1	27.1
1979	27.1	27.1	27.1	27.1
1980	29.1	29.1	29.1	29.1
1981	35.3	35.3	35.3	35.3
1982	38.7	38.7	38.7	38.7
1983	39.2	39.2	39.2	39.2
1984	39.2	39.2	39.2	39.2
1985	37.5	37.5	37.5	37.5
1986	36.1	38.1	35.6	36.1
1987	36.0	40.0	33.8	36.0
1988	36.0	42.0	31.9	54.0
1989	36.0	44.0	30.0	54.0
1990	36.1	46.1	28.2	54.2
1991	36.4	48.4	26.3	54.6
1992	36.8	50.8	24.4	55.2
1993	37.1	53.1	22.5	55.7
1994	37.5	55.5	20.7	56.2
1995	37.9	57.9	18.8	56.8

1/Canadian real fuel pump prices increase at 2 1/2¢/year/liter above that predicted in the Base Case; U.S. prices stay as in Base Case.

2/U.S. and Canadian real fuel pump prices decline steadily to 50% of the 1984 levels by 1995.

3/U.S. and Canadian real fuel pump prices increase 50% in 1988.

TABLE 5-9
MARKET SHARES BY SIZE CLASS
IN CANADA
ALTERNATIVE FUEL PRICE SCENARIOS
(Percent)

Scenario 2

<u>Year</u>	<u>Mini Compact</u>	<u>Sub Compact</u>	<u>Compact</u>	<u>Intermediate</u>	<u>Large</u>
1986	1.4	44.0	19.1	22.9	12.6
1988	3.7	45.7	18.0	22.1	10.5
1990	4.9	48.3	16.2	21.9	8.7
1992	6.4	50.5	14.8	21.0	7.3
1995	7.6	54.0	12.8	20.0	5.6

Scenario 3

<u>Year</u>	<u>Mini Compact</u>	<u>Sub Compact</u>	<u>Compact</u>	<u>Intermediate</u>	<u>Large</u>
1986	1.3	41.7	19.8	23.1	14.2
1988	4.3	53.7	14.4	21.7	5.9
1990	6.0	52.9	14.2	21.7	5.8
1992	6.7	52.7	14.2	21.0	5.4
1995	7.6	53.5	14.0	20.9	4.9

Scenario 4

<u>Year</u>	<u>Mini Compact</u>	<u>Sub Compact</u>	<u>Compact</u>	<u>Intermediate</u>	<u>Large</u>
1986	1.3	41.1	20.0	23.2	14.4
1988	2.8	34.6	21.8	23.3	17.5
1990	1.6	30.4	22.8	24.7	20.5
1992	--	25.3	24.5	26.2	24.0
1995	--	11.7	27.0	32.2	29.1

TABLE 5-10

6. PROJECTIONS OF CORPORATE AVERAGE FUEL CONSUMPTION AND REVIEW OF POLICY IMPLICATIONS

Using the fuel consumption projections by manufacturer and size class developed in Section 4 and the market share forecasts discussed in Section 5, we prepared estimates of Corporate Average Fuel Consumption (CAFC) for the Base Case and each of the three alternative fuel price cases (Scenarios 2, 3, and 4). In addition, we also analyzed CAFC under a fifth fuel price scenario in which fuel pump prices in Canada were assumed to remain constant (as in the Base Case) while U.S. prices fell (as in the "world falling oil price" case of scenario 3). A separate "worst case" scenario (Scenario 6) was included to reflect a case where no further technological improvements beyond those planned for 1988 are employed and the size class mix is equivalent to Scenario 4. Section 6.1 summarizes the CAFC projections by manufacturer for each case. Section 6.2 examines the implications of alternative policies on CAFC forecasts for the Base Case and the "world falling oil price" (Scenario 3) case.

6.1 SUMMARY OF CAFC PROJECTIONS BY FUEL PRICE SCENARIO

Table 6-1 summarizes the CAFC projections by manufacturer under the Base Case, a steady fuel price growth case (Scenario 2), a "world falling" oil price case (Scenario 3), a price "shock" case (Scenario 4). (Fuel price trajectories for each of these four cases were shown earlier in Figure 5-2). In addition, CAFC projections are presented for a fifth fuel price case (Scenario 5) in which fuel pump prices in Canada remain constant (as in the Base Case) while U.S. prices fall (as in the "world falling oil price" case of Scenario 3).

TABLE 6-1
CORPORATE AVERAGE FUEL CONSUMPTION
(l/100 km)

<u>All Domestic Manufacturers</u>					
1986	8.33	8.19	8.36	8.34	8.36
1988	7.85	7.58	8.19	7.57	8.08
1990	7.26	6.85	8.03	6.63	7.77
1992	6.68	6.19	7.86	5.95	7.38
1995	6.20	5.61	7.82	5.19	7.11

It is useful to understand the underlying forces that cause such changes. EEA separately calculated a hypothetical scenario--Scenario 6--that assumes fuel prices identical to Scenario 4 and also assumes that manufacturers will stop the introduction of all new technologies after 1988 (i.e., after the introduction of technologies that are already in a very advanced state of planning). Though this scenario is unrealistic, it is useful to compare the results obtained to those from Scenario 4. Table 6-2 shows that the difference in fuel economy between Scenario 4 and 6, showing that for domestic manufacturers as a whole, fuel consumption declines from 8.36 to 7.82 l/100 km in Scenario 4 even as fuel prices decline, whereas in Scenario 6, fuel consumption increases to 8.88 (l/100 km). This illustrates that even at very low fuel prices there are some "cost-effective" technologies available that are likely to be introduced for competitive reasons. These improvements include electronic control, engine friction reduction, improvements to tires and oils, and drag reduction.

Figure 6-1 illustrates the average CAFC obtained by domestic manufacturers under all six scenarios. The "base" case shows a fairly dramatic decline in CAFC of about 25 percent between 1986 and 1995, inspite of "flat" fuel price expectations. The reasons behind this decline are:

- The momentum of product plans formulated after the 1979 price shock will continue to be felt in the 1986-1988 time frame
- International competition will require technological improvements in cars smaller than the compact size, which account for nearly 2/3 of the Canadian market
- A large number of technological improvements are "cost-effective" even in the U.S., as long as fuel prices are above U.S. \$1 per gallon (1985 dollars)

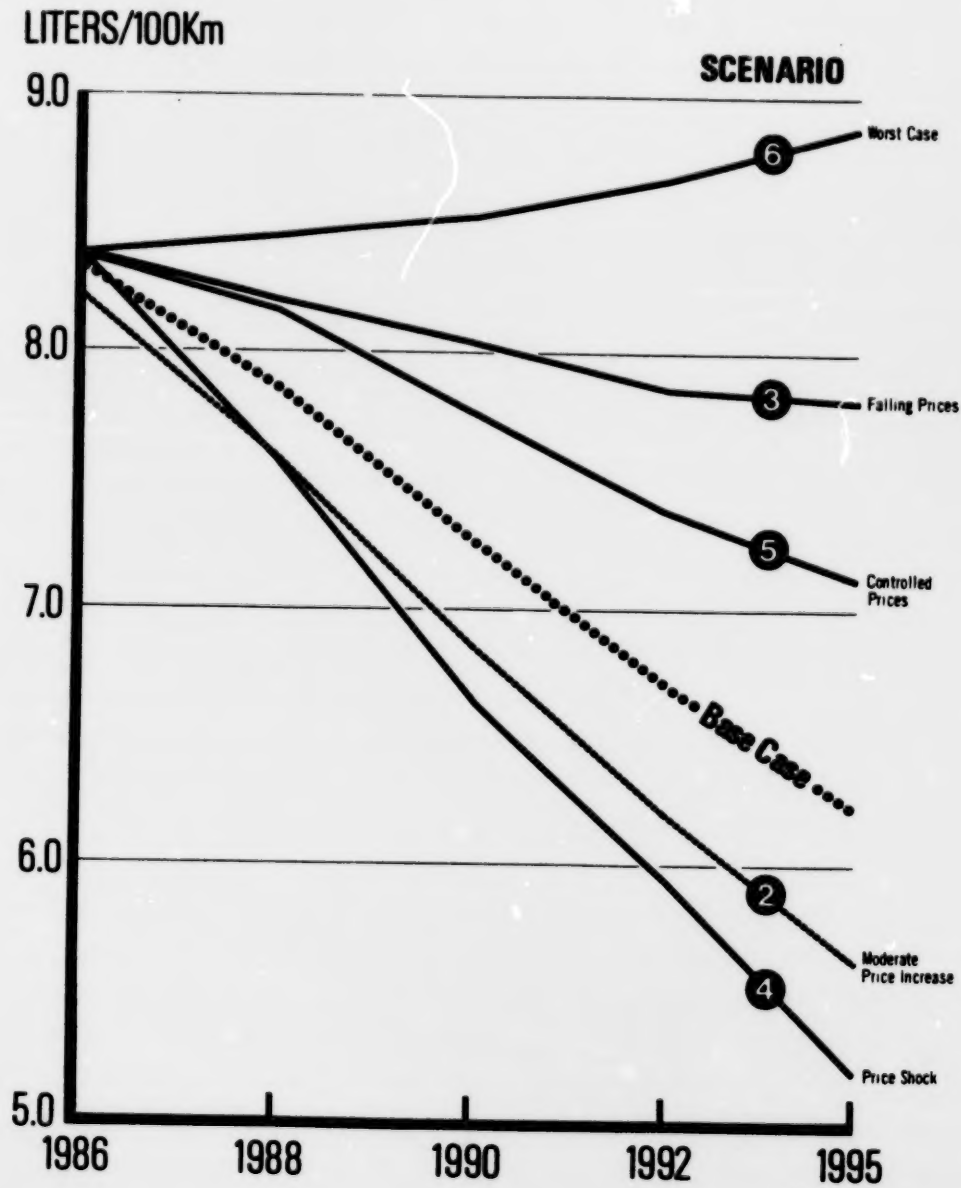
TABLE 6-2

	<u>All Domestic Manufacturers</u>	
1986	8.36	8.36
1988	8.19	8.44
1990	8.03	8.53
1992	7.86	8.68
1995	7.82	8.88

*No technological improvements after 1986

FIGURE 6-1

ALL DOMESTIC MANUFACTURERS
Corporate Average Fuel Consumption
ALTERNATIVE SCENARIOS



The price shock case forces the consumer and manufactures to alter their response and results in a fuel economy decline of 38 percent over the 9 years between 1986 and 1995. This arises from changed consumer preference for smaller cars and less performance, and manufacturers changed tooling plans to introduce fuel efficient products. Scenario 2 can be considered as a case where consumer buying habits are similar to the price shock case, but technological offerings are similar to the base case. The curves in Figure 6-1 show that consumers are responsible for about half the difference in fuel consumption between the price shock and base case. A similar conclusion can be reached if the results of Scenario 5, constant Canadian prices but declining U.S. prices are compared to Scenario 3, where both Canadian and U.S. prices are falling. This shows that Canada can obtain only 50 percent of the total benefit available from a given fuel price change above a base level if U.S. prices remain unchanged from that base level.

6.2 EVALUATION OF POLICY OPTIONS

The results of the analysis were the basis for the evaluation of a number of policy options that are available to the Canadian government to improve fuel economy of cars. Since model specific detail was available, we were able to evaluate more specific policies aimed at vehicles with relatively high fuel consumption characteristics.

The first "option" is the trivial do-nothing case, where the Canadian government has no voluntary agreement with the manufacturers and allows the free market to operate. Our analysis shows that even if fuel prices remain flat in Canada and rise back to 1982 levels by 1995 in the U.S. in real terms, fuel economy will continue to improve by 2 to 3 percent a year over the next decade. Given that the fuel price expectations are considered reasonable, it appears that the free market philosophy may be adequate for Canada. If fuel prices decline sharply in the U.S. and Canada over the next decade--a real possibility--it appears that little

or no improvement in fuel economy will occur inspite of the large amount of "available" technology. A Canadian tax policy to maintain fuel prices at constant levels in real terms will result in Canadian fuel economy showing about half the improvement that is shown in the base case, as U.S. fuel prices will be unaffected by such policies and their decline will influence manufacturer tooling plans. The Canadian consumer then will not receive the benefit of technology that will be cost-effective at Canadian prices. Clearly, any policy options available must seek to guard against the risks of a substantial fuel price decline.

In consultation with EMR, Canada, EEA developed a number of policy variations to evaluate their influence upon the Canadian market, given the "base case" forecast of significant improvements in fuel economy under a flat fuel price scenario. The policies studied were:

- The impact of gas guzzler tax
- The effectiveness of a weight tax
- the effect of forcing large mandatory improvements in fuel economy, either on a size class specific basis or CAFE basis, through a regulatory program
- The influence of import restraints on Japanese or Asian automobiles

Our analysis of these policies is described in the following subsections.

6.2.1 Impact of a Gas Guzzler Tax

In 1978 the Congress of the United States passed a law which required all new automobiles with a fuel economy falling more than 5 miles per gallon below the applicable Corporate Average Fuel Economy (CAFE) standard to be subject to a "gas guzzler" tax. The intent of the legislation was to discourage consumers from purchasing fuel inefficient cars and thereby improve CAFE.

The impact of the U.S. gas guzzler tax schedule (shown in Table 6-3) on the Base Case CAFC projections for Canada was briefly analyzed. This analysis showed that the U.S. gas guzzler schedule would have little impact on Canadian CAFC. In fact, in 1986, only 3 percent of total Canadian car sales would be subject to a guzzler tax using the U.S. scheme. By 1990, this percentage would decline to about 2 percent. The gas guzzler cars would be limited primarily to the Chevrolet Corvette and some large-size Ford models -- vehicles with relatively small sales volumes. Previous history suggests that manufacturers will make some minor technological improvements on such models to effectively "beat" this tax.

As an alternative approach, we analyzed the impact of a hypothetical gas guzzler tax schedule proposed by Energy, Mines, and Resources, Canada (see Table 6-4) that is far more stringent. Based on this schedule, approximately 28.2 percent of total Canadian car sales in 1986 will be subject to a gas guzzler tax in the Base Case (see Table 6-5). With the overall trend in the base case towards decreasing fuel consumption in the future, this percentage will decline to 7.2 percent by 1990 and 2.2 percent by 1995. As shown in Table 6-6 the distribution of vehicles in each fuel consumption category subject to a guzzler tax also will shift downward as the overall average fuel consumption declines over time.

Estimation of the impact of the gas guzzler tax on CAFC requires some knowledge of the sensitivity of new car buyers to changes in new car prices. For example, buyers of the Cadillac DeVille or the Chevrolet Corvette are likely to be less price sensitive than buyers of the Chevrolet Chevette or the Ford Escort. For the purpose of this analysis, vehicle size class price elasticities were drawn from a model of U.S. car sales developed by Oak Ridge National Laboratory (ORNL) with the implied assumption that Canadian new car buyers have price sensitivities

TABLE 6-3

U.S. GAS GUZZLER TAX, ENERGY TAX ACT OF 1978

Miles per Gallon ^a At Least-Less Than	1980	1981	1982	1983	1984	1985	1986
0-12.5	\$550	\$650	\$1,200	\$1,550	\$2,150	\$2,650	\$3,850
12.5-13.0	550	650	950	1,550	1,750	2,650	3,200
13.0-13.5	300	550	950	1,250	1,750	2,200	3,200
13.5-14.0	300	550	750	1,250	1,450	2,200	2,700
14.0-14.5	200	450	750	1,000	1,450	1,800	2,700
14.5-15.0	200	450	600	1,000	1,150	1,800	2,250
15.0-15.5	0	350	600	800	1,150	1,500	2,250
15.5-16.0	0	350	450	800	950	1,500	1,850
16.0-16.5	0	200	450	650	950	1,200	1,850
16.5-17.0	0	200	350	650	750	1,200	1,500
17.0-17.5	0	0	350	500	750	1,000	1,500
17.5-18.0	0	0	200	500	600	1,000	1,300
18.0-18.5	0	0	200	350	600	800	1,300
18.5-19.0	0	0	0	350	450	800	1,050
19.0-19.5	0	0	0	0	450	600	1,050
19.5-20.0	0	0	0	0	0	600	850
20.0-20.5	0	0	0	0	0	500	850
20.5-21.0	0	0	0	0	0	500	650
21.0-21.5	0	0	0	0	0	0	650
21.5-22.0	0	0	0	0	0	0	500
22.0-22.5	0	0	0	0	0	0	500
22.5+	0	0	0	0	0	0	0

^aCombined City/Highway rating.

Note: New car purchaser pays tax if car's combined city/highway fuel economy rating is significantly, generally 5 mpg, below the standard for that year.

SOURCE: Energy Tax Act of 1978, Public Law 95-618, Gas Guzzler Tax.

TABLE 6-4

ANALYSIS OF EMR PROPOSED GAS GUZZLER TAX
ON CAFC PROJECTIONS FOR THE BASE CASE

<u>Fuel Consumption Category (l/100km)</u>	<u>Guzzler Tax</u>
Less than 8.5	\$ 0
8.5 - 9.0	\$ 500
9.0 - 9.5	\$ 750
9.5 - 10.0	\$1,000
10.0 - 10.5	\$1,250
10.5 - 11.0	\$1,500
11.0 +	\$2,000

TABLE 6-5

PERCENT OF TOTAL CANADIAN CAR SALES
SUBJECT TO A GUZZLER TAX IN THE
BASE CASE

<u>Size Class</u>	<u>1986</u>	<u>1988</u>	<u>1990</u>	<u>1992</u>	<u>1995</u>
Minicompact	0	0	0	0	0
Subcompact	0	0	0	0	0
Compact	4.0	1.7	1.7	0	0
Intermediate	14.8	9.5	1.6	1.4	0
Large	<u>9.4</u>	<u>9.2</u>	<u>3.9</u>	<u>3.1</u>	<u>2.2</u>
TOTAL	28.2	20.4	7.2	4.5	2.2

TABLE 6-6

DISTRIBUTION OF TOTAL (DOMESTIC AND IMPORT)
CAR SALES IN CANADA BY FUEL
CONSUMPTION CATEGORY
BASE CASE
(percent)

<u>Fuel Consumption Category (l/100 km)</u>	<u>1986</u>	<u>1988</u>	<u>1990</u>	<u>1992</u>	<u>1995</u>
less than 8.5	71.8	79.6	92.8	95.5	97.8
8.5 - 9.0	4.8	14.7	2.4	2.3	0.2
9.0 - 9.5	14.9	2.9	2.5	--	--
9.5 - 10.0	4.5	0.4	--	0.2	2.0
10.0 - 10.5	--	0.2	0.2	2.0	--
10.5 - 11.0	0.5	--	2.1	--	--
11.0 +	<u>3.5</u>	<u>2.2</u>	<u>--</u>	<u>--</u>	<u>--</u>
TOTAL	100.0	100.0	100.0	100.0	100.0

that are similar to the U.S. new car buyers.* These elasticities ranged from -0.4 for intermediate sized economy cars to -2.5 for large (i.e., standard) automobiles such as the Chevrolet Impala, and Parisienne.

A second component in the analysis concerned the criteria for determining the impact of a tax-induced price increase on a given model on the demand for other models. Essentially, this analysis required the use of cross-price elasticities to evaluate the impact of changes in the sales of fuel efficient models in Canada due to increases in the price of gas guzzlers. Given the paucity of data available on cross-price elasticities we assumed the following:

- All models within each vehicle size class were ranked according to their fuel consumption and price characteristics
- Increases in the price of a vehicle due to a gas guzzler tax were assumed to result in a shift in sales to the next most fuel efficient vehicle available (regardless of make at a comparable price)

The results of the analysis are shown in Table 6-7. A gas guzzler tax will reduce Base Case total CAFC by 1 percent (0.1 l/100km) in 1986 -- the year of maximum impact. By 1990, gas guzzler tax will reduce Base Case total CAFC by 0.3 percent (0.02 l/100km), and by 1995 the impact will be negligible as only a few guzzlers will continue to be produced.

*David Green, Oak Ridge National Laboratory, "A State of Level Stock System Model of Gasoline Demand," prepared for the U.S. Department of Energy, 1981.

TABLE 6-7

TABLE 6-7

The results displayed in Table 6-7 should, however, be interpreted with some caution. They assume that there will be no significant manufacturer response to avoid the "stigma" of a gas guzzler tax by accelerating technology introduction. In reality, the impact of the gas guzzler tax in the U.S. has been precisely to motivate manufacturers to improve fuel economy on specific models to avoid the "guzzler" label. Although the manufacturer response to a gas guzzler tax is extremely difficult to quantify, the fuel savings from such a tax will likely be more substantial than those shown in Table 6-7, if the response was accounted for. Secondly, the assumptions on model shifting are guaranteed to result in relatively small changes in net CAFC. The purpose of the calculation is, however, to show that under the Base Case, the tax will have only a small influence on fuel consumption, especially in the 1990-1995 period.

Unlike the Base Case, a gas guzzler tax will have a larger impact in an environment of falling fuel prices, simply because the market will be sending signals to producers and consumers to manufacture and buy less fuel efficient cars. As a result, a larger percentage of new cars will be subject to the gas guzzler tax. This is amply demonstrated in Table 6-8 which shows the percentage of new vehicle sales that would be taxed using the EMR guzzler schedule listed earlier in Table 6-4. Under the falling world oil price case, 33.6 percent of Canadian car sales will be subject to a gas guzzler tax. By 1995, the guzzler share will drop to 22.9 percent. This compares with shares of 28.2 percent and 2.2 percent for 1986 and 1995, respectively, in the Base Case and reflects the difference in overall fuel consumption trends between the two fuel price scenarios.

Using the same assumptions and methodology as in the Base Case, we estimated the impact of a gas guzzler tax on CAFC in the world falling oil prices case, but the results still did not show any substantial impact.

TABLE 6-8

However, the same caveat made for the Base Case guzzler tax is perhaps even more relevant in the Falling Fuel Prices scenarios. That is, it is highly unlikely that the automobile manufacturers will tolerate a situation in which 23-25 percent of their automobiles are labeled as "guzzlers". A gas guzzler tax imposed in a Falling Fuel Prices scenario will likely accelerate technology introduction as manufacturers strive to avoid the "stigma" of a guzzler label on their models. In this respect, the guzzler tax will serve primarily as a floor for CAFC--particularly if the tax schedule is not shifted over time to account for the falling trend in CAFC.

The analysis indicates that a gas guzzler tax is likely to have virtually no effect in the long term if fuel prices stay relatively constant, but have substantial effect if fuel prices fall. Additionally, the burden of the tax will fall only the least efficient vehicles, whose price and characteristics lend to further improvements. If fuel prices decline, the gas guzzler tax affects a significant percentage of the fleet--a level that appears likely to influence manufacturer product decisions. Although the nature and extent of this influence is difficult to predict, EEA believes that, at the very least, efficient combinations of engines and drivetrains will be developed for Canada; for large selling models (such as GM's A-body which Canada builds for both the domestic and U.S. markets) it is possible that manufacturers would seriously consider major technological improvements (as in the base case) even if fuel prices in the U.S. are low.

6.2.2 Effectiveness of a Weight Tax

Traditionally the size of a vehicle has been used as a simplistic measure of its fuel efficiency; the larger the vehicle the less efficient it is perceived to be. In many countries ownership taxes have been based on a vehicle's weight; this is true in numerous states of the U.S. and several European countries. Weight is also a measure of the wear a vehicle

inflicts on a road system and has been used as a basis for equitably assessing maintenance funds. Historically weight has also been used as a measure of luxury for cars, generally speaking the heavier the car the more options and appointments it is likely to contain and the greater the cars value.

The trouble with using weight as a measure of efficiency, highway damage or luxury is that it is only generally correlated with each of these variables. There are many examples where vehicle weight does not accurately capture the intended value: the large car with an efficient diesel engine, the heavy truck that travels only 1000 miles in a year and the light weight high performance car.

Weight has been suggested as the basis or metric for developing a tax to stimulate fuel efficiency, in the sense of a gas guzzler tax based on weight. As discussed above the problem with using weight as a surrogate measure of a vehicle's fuel efficiency is that it often does not accurately capture the intended measurement value. Weight is a significant determinant of a vehicle's efficiency but it is not the only determinant. Given two vehicles of comparable size, the heavier vehicle is not necessarily the less efficient one. Improvements in the engine, drivetrain, transmission, or lubricants of one can more than offset the weight difference and allow it to have the superior fuel efficiency.

Table 6-9 provides a summary of the weights of Canadian vehicles (using Base Case values) that are subject to the U.S. gas guzzler tax. In 1984 only two vehicles fall below the efficiency cut point of 12.06 l/100 km, one weighs 3100 lbs and the other weighs 3800 lbs. Surprisingly a large number of vehicles weighing more than 3100 lbs are not captured by the tax. In fact one vehicle weighing 4100 lbs achieves a fuel efficiency of 11.82 and is not subjected to the tax based on efficiency. That vehicle (a GM C-Body) weighs 1000 lbs more than the Corvette (GM Y-Body) but still achieves a superior fuel consumption rating.

TABLE 6-9
WEIGHT OF VEHICLES SUBJECT
TO U.S. GAS GUZZLER TAX

<u>Year</u>	<u>U.S. Gas Guzzler Tax Cut Point</u>	<u>Carline Platform</u>	<u>FC</u>	<u>Weight</u>
1984	12.06	GM Y-Body*	12.07	3100
		Ford Panther*	12.20	3800
1986	10.45	GM Y-Body	10.78	3100
		Ford Panther	11.62	3800
		Ford B-Body	10.69	3700
1988	10.45	Ford Panther	11.30	3800
1990	10.45	Ford Panther	10.97	3800

*Minor technological improvements to these vehicles in the U.S. resulted in their being certified at levels slightly below the cut-point.

Table 6-10 provides a summary of the range of fuel consumption values associated with specific weight classes in 1984 vehicles. The weight categories are defined in 1000 lb increments and are listed only when vehicles exist within the category. Generally fuel efficiency follows weight. However, enough anomalies exist, where more efficient vehicles occur in a higher weight category, to suggest that weight is an inequitable measure of a vehicle's efficiency. In the 3100 to 3200 lb category the range of efficiency is 1.82 l/100 km or over a 15 percent variation in the efficiency of the midpoint of the range.

To find out whether the range of fuel efficiency variations diminishes over time as vehicle weight declines and vehicles are expected to become more homogenous a similar table was created for 1990 vehicles (using Base Case forecasts). The data shown in Table 6-11 indicates that while the overall weight range of vehicles diminishes, the range of efficiency within and between specific weight contiguous categories remains. In fact the variation in efficiency within weight categories is forecast to increase, not decrease.

Another major consideration is that our calculations show that weight reduction through material substitution as one of the least "cost-effective" of technologies, as the cost of material substitution exceeds the benefits of fuel savings at low or moderate fuel prices. A weight tax would have the effect of encouraging this technology potentially at the expense of other, more cost-effective, technologies.

In summary weight has been shown to be an inexact measure of fuel efficiency. If a tax is to be employed to encourage either the production or ownership of fuel efficient vehicles, it should be based on a direct measure of the vehicles' fuel consumption, not its weight, nor encourage less cost-effective technology.

TABLE 6-10
RANGE OF FUEL EFFICIENCIES ASSOCIATED WITH
SPECIFIC WEIGHT CLASSES IN 1984

<u>Weight Category</u>	<u>Range of Fuel Consumption Values</u>
2000 and under	6.28
2100 - 2199	6.67
2200 - 2299	6.96 - 7.49
2400 - 2499	7.48 - 8.38
2500 - 2599	8.32
2600 - 2699	8.30 - 8.47
2900 - 2999	10.07
3000 - 3099	9.44 - 9.63
3100 - 3199	10.24 - 12.07
3200 - 3299	10.20
3700 - 3799	11.21 - 11.33
3800 - 3899	11.48 - 12.2
4100 and up	11.82

TABLE 6-11
RANGE OF FUEL EFFICIENCIES ASSOCIATED WITH
SPECIFIC WEIGHT CLASSES IN 1990

<u>Weight Category</u>	<u>Range of Fuel Consumption Values</u>
1700 - 1799	5.23
1800 - 1899	5.99
2000 - 2099	5.83
2200 - 2299	5.81 - 7.24
2400 - 2499	7.75
2500 - 2599	7.44 - 7.94
2600 - 2699	7.73
2700 - 2799	7.37
2800 - 2899	7.73 - 8.60
2900 - 2999	8.08 - 10.30
3000 - 3099	7.93
3200 - 3299	8.29 - 9.19
3300 and up	8.47 - 10.97

6.2.3 Effect of Regulations Mandating Fuel Consumption Reduction

EEA's forecasts have shown that under the appropriate fuel prices, sufficient technology exists to provide large reductions in fuel consumption. Since the "base case" forecast itself showed CAFC improvement of 2 to 3 percent per year we analyzed the implications of mandating a very large increase of 5 percent/year, on average, on both a size class specific and CAFC basis. It was assumed that fuel prices remained as in the base case. In this analysis, EEA calculated the incremental price impact associated with meeting the targets, not an annual basis, but at 1995, starting from 1984 as the base year. The price impact is the incremental change in retail prices associated with the introduction of new technology, starting from 1984 as the price baseline. The prices are calculated in constant 1981 U.S. dollars, which was the basis for all of our "cost-effectiveness" calculations in the TCSM.

At the outset of the analysis, it was obvious that substantial technological improvements were needed over and above these in the base case to meet the targets. The analysis of size class specific targets was assumed equal to the analysis of model specific targets, i.e., it was assumed that all models were subjected to this regulation and manufacturers did not attempt a significant shift in the model mix within size class. Available technologies were then chosen in the order of decreasing cost-effectiveness to meet the target. It was found that cars that had been recently redesigned required more technology (higher incremental costs) to meet the target. A diesel penetration of 20 to 30 percent was required to meet targets on most vehicles. Since diesels are unlikely to be used in sports cars, it was found that many sports cars were unable to meet the targets (although they were generally within 5 percent of the target) even with all available technology except diesels being used. Since mini-compacts were very fuel efficient to begin with, the targets were impossible to meet for these vehicles; consultations with EMR, Canada resulted in our exempting the minicompacts from the 5 percent/year fuel economy improvement.

The purpose of the analysis was twofold:

- Examine, if in fact, such a high level of fuel efficiency could be obtained
- Estimate the level of price increase that would accompany these increases in efficiency so that it is possible to define criteria under which such regulation should be implemented

It must be noted that the targets can be met only with major vehicle redesign. Automanufacturers would face a substantial disruption of current product plans to meet such conditions targets and it appears unlikely that manufacturers will do so just to meet Canadian regulations.

TABLE 6-12

The above results provide the incremental price impact for each carline to obtain the target. The following points must be noted:

*This is due to the presence of sports cars in these classes that do not meet the targets.

TABLE 6-15

- In all cases, meeting the 1995 target requires major vehicle redesign with lightweight materials (aluminum, composites), extensive use of small size, high output engines and a diesel penetration of 20 to 30 percent.
- Some sports cars, where diesel sales are unlikely do not meet the targets. Exceptions are the Corvette, where we assumed a major weight reduction program and the use of 6-cylinder/4-valve engine to meet the target, and the Mustang which we assumed will be converted to FWD.
- The requirement of increasing fuel economy by a given percentage starting from a 1984 or 1985 baseline provides an advantage to manufacturers who have older, less fuel efficient products in that size class in the base year..

One method of implementing the mandatory 5 percent/year CAFC improvement that was not considered is to cause a forced shift in size class mix, potentially by aggressive pricing of larger vehicles. This allows manufacturers a large number of possible technology/mix combinations to meet CAFC targets. For example, it is possible to meet CAFC targets of 5.15 km/l (which represents a 5 percent/year improvement starting from 8.6 in 1985) in 1995 with just the base case level of technology by phasing out large cars and moving the mix so that at least 60 percent of vehicles sold are in the subcompact and minicompact classes. The effect of placing such stringent restrictions on consumer choice were considered to be beyond the scope of this report, but is worthy of future consideration under fuel shortage conditions.

We also note that decreasing the fuel consumption from 8.6 l/100 km to 5.15 l/km saves \$1170 (U.S.) per average car if fuel prices are U.S. \$0.50/liter and U.S. \$585 per average car if fuel prices are U.S. \$0.25/liter, calculated over the first 4 years of a cars life using a 10 percent discount rate. The savings associated with these fuel prices bracket the range of expected increases in incremental costs indicating that the increases are possible at high fuel prices. In fact, the fuel price shock scenario results in a CAFC forecast only slightly higher than the desired 5.15 l/100 km, and does not utilize a very high diesel

penetration because of the shift in size mix associated with higher fuel prices.

6.2.4 Removal of Import Restraints for Japanese Vehicles

The removal of import restraints provides the Japanese with the opportunity to not only increase their market share but shift the distribution of the vehicles they market. Each of these changes can have a separate impact on CAFC levels. Because changes in Japanese marketing strategies will stimulate a competitive response from domestic manufacturers, changes in the price and distribution of their products must also be considered in the CAFC analysis. Such an analysis is neither simple nor straightforward. This discussion is organized to provide a summary of domestic and Japanese CAFC performance in Canada and U.S. for the last 5 years, an outline of the issues to be considered in a CAFC effects analysis, the results of a recent U.S. analysis of import restraints and related CAFE impact, and the results of an analysis of Canadian CAFC levels under three scenarios in 1995.

The simultaneous institution of import restraints for Japanese vehicles in Canada and the U.S. in 1982 allows a relevant comparison of sales and efficiency levels between both countries. Table 6-16 provides a summary of the Japanese and domestic manufacturer efficiency levels in both countries from 1980 to 1984. Similar trends occur in Japanese vehicles in both Canada and the U.S. over the years of the import restraints: weight increases and market share moderates. In Canada, the efficiency of Japanese vehicles appear to level off and even slightly decline between 1983 and 1984. On the other hand, the efficiency of Japanese vehicles in the U.S. increases steadily.

The fuel consumption values and weight of domestic vehicles in both Canada and the U.S. declined over the 5 year period, reflecting government pressure and consumer demand for vehicles with increased efficiency.

TABLE 6-16
COMPARISON OF JAPANESE AND DOMESTIC SALES AND
EFFICIENCY STATISTICS FOR CANADA AND U.S.

<u>CANADA</u>						
	<u>Japanese</u>			<u>Domestic</u>		
	<u>% of total Sales</u>	<u>Weight</u>	<u>l/100 km</u>	<u>% of total Sales</u>	<u>Weight</u>	<u>l/100 km</u>
1980	11.5	2336	7.55	81.6	3363	10.84
1981	21.8	2363	7.40	71.5	3276	9.95
1982	26.1	2385	7.23	64.2	3051	9.01
1983	22.8	2397	6.97	70.9	3047	9.01
1984	18.5	2401	7.03	73.3	3030	8.81

<u>U.S.</u>								
	<u>Japanese</u>				<u>Domestic</u>			
	<u>% of Total Sales</u>	<u>Weight</u>	<u>l/100 km</u>	<u>Average Price (\$)</u>	<u>% of Total Sales</u>	<u>Weight</u>	<u>l/100 km</u>	<u>Average Price (\$)</u>
1980	20.6	2482	8.11	7492	72.9	3319	10.69	7630
1981	22.4	2469	7.61	8892	71.6	3288	10.01	8,929
1982	23.4	2512	7.54	9660	70.3	3244	9.60	9,889
1983	23.1	2521	7.13	10,829	70.6	3326	9.72	10,504
1984	20.5	2519	7.02	11,954	72.9	3281	9.37	11,059

The Canadian domestic vehicles are typically slightly more efficient than their counter parts in the U.S. due to the greater proportion of small car sales in Canada.

One of the most telling statistics in the table is the change in the average price of Japanese and domestic vehicles in the U.S. over the 1980-1984 period. The Japanese vehicles go from a \$138 price advantage in 1980 to a \$895 disadvantage in 1984. This occurs in the face of the often cited \$2500/car production cost advantage that Japanese manufacturers enjoy over domestic manufacturers. This change clearly reflects the impact of the voluntary restraint agreement (VRA) on the mix and price of Japanese vehicles offered for sale. Surprisingly the efficiency level of the Japanese vehicles in the U.S. has continued to improve while the Japanese vehicles in Canada appear to have flattened out at least temporarily.

Issues to be considered when evaluating the CAFC effects of removing import restraints are:

- Japan's approach to quota's after removal of restraints
- Price advantage of Japanese vehicles vis-a-vis domestic vehicles
- Segment of the market Japanese manufacturers target for a sales increase
- Market conditions after removal of restraints
- Ability of domestic manufacturers to compete

The extensive debate in the U.S. and Japan about the acceptable level of imports into the U.S. after the elimination of VRA indicates that a wide range of possible sales levels exist and that a completely free and open market still will not necessarily occur. The margin of sales determined to be acceptable over the current levels governed by restraints will have a substantial impact on the price and the type of vehicles Japanese manufacturers target for expansion. Obviously a small sales increase is unlikely to have a significant effect on the price, the size distribution or the fuel efficiency of the Japanese fleet.

The key advantage of Japanese manufacturers rests in their ability to produce vehicles with a \$2500 price advantage over domestic manufacturers. This allows them to enter or expand the sales of any vehicles they currently produce with relative ease. They have the ability to shift the distribution of their sales from high priced relatively less fuel efficient models to lower priced relatively more efficient vehicles if that approach allows them to maximize profits through volume sales.

Another issue that will influence the Japanese marketing strategy will be the general market conditions that prevail in the future. Their response will likely differ under each of the scenarios considered in this analysis, just as the domestic manufacturers response will. To simplify the consideration of the CAFC effects only one scenario was evaluated: the Base Case.

A final consideration is the ability of the domestic manufacturers to respond to Japanese changes in the price and distribution of their products. The U.S. Council of Economic Advisors (CEA) recently conducted an analysis^a of the effects of the voluntary restraint agreement and the potential CAFE impacts of its removal. A review of the results of that study are useful because it provides an outline of the range of possible impacts likely to occur (from a CAFE/CAFC perspective) in both the U.S. and Canada and it provides insight into the likely response of domestic manufacturers in both countries.

^aMemorandum; To: The Trade Policy Review Group; From: William A. Niskanen; Subject: Effects of Voluntary Restraint Agreement, Council of Economic Advisors, January 24, 1985.

Overall, the study looked at the effects of VRA on Japanese automobile exports to the U.S. It also examined the effects of U.S. CAFE regulations on the automotive market and the interaction of VRA and CAFE regulations. The effects of changes in these policies were evaluated for the following variables:

- Prices of U.S. and Japanese automobiles
- Domestic automobile production and U.S. assemblies of Japanese automobiles
- New-car average fuel economy for U.S. cars and for U.S. and foreign cars combined
- Automotive industry employment
- Consumer welfare and foreign producer earnings

Two scenarios were examined: 1) VRA eliminated, CAFE regulation non binding; and 2) VRA eliminated, CAFE regulations are maintained at 26 mpg for the future. The results are as follows:

- 1) The elimination of the VRA increases the supply of Japanese small cars and depresses prices and sales of U.S. small cars. This is estimated to have little effect on the sales of large cars. Overall, the U.S. fleet average fuel economy falls, but by only 0.1 mpg. Because the increase in sales of Japanese small cars is greater than the decrease in sales of U.S. small cars the average mpg of all cars sold increases 0.4 mpg.
- 2) In this scenario the U.S. manufacturers reprice their cars to shift sales from large to small cars in the face of increased supplies of Japanese imports and CAFE requirements. The average fuel economy of the U.S. fleet increases by 0.7 mpg. Overall the fuel economy of all cars sold increases by 0.9 mpg due to the increase in the efficiency of the U.S. fleet and the increases sales of Japanese cars.

The CEA analysis indicates that the elimination of VRA is going to increase the supply and sales of small Japanese cars and significantly increase the competition for domestic manufacturers in the small end of the market. Both scenarios lead to an increase in the new car fleet efficiency level but the effects are relatively modest and range from 0.4 to 0.9 mpg. In both cases domestic manufacturers are forecast to retain the large car

share of the market and to compete in the small car share with reduced prices if necessary. The consumer appears to be the primary beneficiary through reduced vehicle prices.

To evaluate the affects of removing import restraints on future CAFC levels, a set of scenarios similar to the ones used in the CEA analysis were constructed for Canada in 1990. Two scenarios were developed around the Base Case. One (#1) evaluated the CAFC levels achieved when import restraints were eliminated and fuel efficiency standards were relaxed. The other (#2) evaluated CAFC levels when import restraints were eliminated and fuel efficiency standards were maintained.

Table 6-17 summarizes a forecast of 1995 fuel efficiency levels for domestic and imported vehicles. The bulk of the effort in this project has been devoted to the analysis of the range of domestic fuel efficiency levels likely to be achieved in future years. A similar analysis of imported vehicles is required to correctly quantify their future efficiency levels. The values shown summarize EEA's estimate of Japanese and European efficiency levels; however, they lack the benefit of a detailed supporting analysis (considered beyond the scope of this effort). Basically Japanese vehicles are projected to compete in three size classes--mini, subcompact and luxury. All forecasts of domestic mini vehicles assume them to be captive imports from Japan, therefore their efficiency levels are assumed to be the same. In the subcompact size class the Japanese vehicles are projected to be marginally (about 5 percent) more efficient than domestic vehicles. In the large luxury class however the smaller Japanese vehicles are forecast to have a 23 percent efficiency advantage over larger domestic vehicles. For the sake of simplicity the European vehicles are assumed to have the same efficiency levels as their domestic counter parts, similar to their historical relationship.

The Base Case forecast assumes that import restraints are maintained and that Japanese market share is held to 16.8 percent of the market. Under

TABLE 6-17
 FORECAST OF FUEL CONSUMPTION AND MARKET SHARE
 FOR DOMESTIC AND IMPORTED CARS UNDER BASE CASE
 CONDITIONS IN 1990
 l/100 km, (percent of total market)

<u>Manufacturer</u>	<u>Size Class</u>				
	<u>Mini</u>	<u>Subcompact</u>	<u>Compact</u>	<u>Intermediate</u>	<u>Large</u>
Japan	4.72 (1.1)	5.75 (13.7)	--	--	7.0 (2.0)
Domestic	4.72 (2.9)	6.04 (20.8)	7.56 (19.6)	7.74 (22.7)	9.06 (9.4)
European	--	6.04 (5.2)	--	--	9.06 (2.6)

each of the alternative scenarios, #1 and #2, Japanese manufacturers are assumed to expand to and retain 26 percent of the market in 1990. This expansion is assumed to come completely at the expense of the domestic manufacturers. The Europeans are assumed to retain the 7.8 percent market share outlined in the Base Case. In all of the scenarios the size class specific efficiency levels specified in Table 6-17 are forecast to remain the same.

The results of the shifting sales distributions, under each of the scenarios, on 1990 CAFC levels is shown in Table 6-18. The Base Case shows the Japanese to have substantially better (approximately 20 percent) fuel efficiency than domestic manufacturers. This advantage reflects the smaller size of the Japanese cars as opposed to the greater volume of larger cars for domestic manufacturers. The Europeans maintain a 4.5 percent fuel consumption advantage over the domestic manufacturers even though they are both assumed to achieve the same efficiency level by size class. The fleet of new cars, including imports, is projected to achieve a fuel consumption level of 7.00 l/100 km in 1990.

Under scenario #1, there is a substantial increase in the sales of small Japanese cars, almost 55 percent over the Base Case. There is even an improvement in the aggregate Japanese fuel consumption values reflecting a slight shift toward smaller cars in comparison to the Base Case. On the other hand because fuel efficiency standards are lifted, domestic manufacturers are assumed to sell only larger cars and concede small car sales to the Japanese (a worst case assumption for fuel efficiency). This shift leads to an increase in the average fuel consumption of domestic vehicles from 7.26 to 7.51 l/100 km. The aggregate effect of these two shifts is to produce essentially no impact on the total fleet fuel consumption values as compared to the Base Case. Both shifts appear to cancel each other out with no impact on the national fleet, even though substantial manufacturer specific changes have occurred.

TABLE 6-18
COMPARISON OF CAFC LEVELS ACHIEVED BY DOMESTIC
AND FOREIGN MANUFACTURERS IN 1990 UNDER ALTERNATIVE
SCENARIOS RELATED TO IMPORT RESTRAINTS AND
EFFICIENCY STANDARDS
l/100 km (percent of total market)

<u>Scenario</u>	<u>Manufacturer</u>			
	<u>Japan</u>	<u>Domestic</u>	<u>Europe</u>	<u>Total</u>
Base Case	5.83 (16.8)	7.26 (75.4)	7.04 (7.8)	7.00
#1, Imports Restraints Eliminated Fuel Efficiency Standards Relaxed	5.73 (26)	7.51 (66.2)	7.04 (7.8)	7.01
#2, Import Restraints Eliminated Fuel Efficiency Standards Maintained	5.73 (26)	7.26 (66.2)	7.04 (7.8)	6.85

In Scenario #2, the Japanese retain the expanded market share due to the elimination of import restraints. The domestic manufacturers are expected to achieve voluntary fuel consumption levels and equal the CAFC values achieved under the Base Case; this leads to a shift in their size class sales distribution. Overall the net effect of these changes in the fleet fuel consumption values is to reduce CAFC levels from 7.00 in the Base Case to 6.85 l/100 km in the case of no restraint, but continued emphasis towards meeting CAFC standards.

In summary the removal of import restraints has been shown to have no substantial influence on national average efficiency levels. The scenarios outlined in this section were designed to illustrate the maximum fuel consumption impacts. While they lead to relatively large shifts in manufacturers market share they had little impact on aggregate manufacturer efficiency levels and even less on national fuel consumption levels. The removal of import restraints is not expected to degrade aggregate CAFC levels and may lead to a slight improvement depending on government policy on future efficiency standards/agreements.

While the removal of import restraints is not expected to have a significant impact on aggregate CAFC levels the influence on individual domestic manufacturers could be substantial. One clear result of removing the restraints will be an increased supply of relatively low cost fuel efficient Japanese cars. All manufacturers competing in the small car market will be effected. The magnitude of this effect on CAFC levels will depend on the distribution of cars they offer to the market. Those manufacturers focusing on the small car market, primarily AMC and Chrysler, will likely suffer a serious erosion of their profitability but are unlikely to experience a significant reduction in the efficiency of their cars. Those full line manufacturers with a significant portion of large car sales are unlikely to suffer a serious loss of profitability (assuming that CAFC levels are no longer force) but they are likely to experience a significant reduction in the efficiency of their new car fleet. That

reduction will be caused through a loss of small car sales due to the increased Japanese competition.

If fuel efficiency agreements are maintained the full line manufacturers will be forced to reprice their smaller cars to achieve the market share necessary to satisfy the agreements. Depending on manufacturers' ability to increase the prices of large cars in the face of declining small car prices their profitability is likely to be reduced, substantially.